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GEORGE C. LLOYD

Secretary

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PREFACE.

The present volume of the *Journal of the Iron and Steel Institute* contains the Presidential Address of Sir Peter Rylands, a "Report on the Heterogeneity of Steel Ingots," prepared by a Committee of the Institute under the Chairmanship of Dr. W. H. Hatfield, and fourteen other papers, all presented at the Annual Meeting held in London, with the discussion and correspondence thereon. Mention should also be made of the fact that in addition to the above mentioned a paper by Dr. W. Rosenhain, F.R.S., Mr. R. G. Batson, and Mr. N. P. Tucker, on "The Effect of Mass in the Heat Treatment of Nickel Steel," was read and discussed, but the publication of it has been postponed until some further confirmatory experiments have been carried out. The proceedings and speeches at the Annual Dinner, held at the Connaught Rooms on June 3, are also reported.

Biographical notes of the careers of members deceased will be found under "Obituary Notices."

Section II. contains, as usual, notes on the progress of the home and foreign iron and steel industries, as reported in the proceedings of scientific and technical societies and in the technical press, together with a short review of new books presented to the Institute, and a bibliography of the principal works dealing with the metallurgy of iron and steel and allied subjects, which have appeared during the past six months.

At the end is inserted a list of the British Standardised Steel Samples, showing where and on what terms these samples are obtainable.

Owing to the General Strike in the first week in May, in which the Annual Meeting usually takes place, it became necessary to postpone the date of the meeting for four weeks. It is to be regretted that for this reason the publication of the volume has been delayed some weeks beyond the usual time.

28 Victoria Street, London, S.W. 1.
September, 1926.

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SECTION I.

MINUTES OF PROCEEDINGS AND PAPERS OF THE IRON AND STEEL INSTITUTE.

ANNUAL MEETING

1926.

Editorial assistance has been given by A. E. Chattin, B.Sc., Assistant Secretary, in the preparation of this Section.

MINUTES OF PROCEEDINGS

AND

PAPERS AND DISCUSSIONS

AT THE

ANNUAL MEETING, 1926.

The Fifty-seventh Annual General Meeting of the Iron and Steel Institute was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday and Friday, June 3 and 4, 1926, under the Presidency of Sir Frederick Mills, Bt., D.L.

The Minutes of the last General Meeting were taken as read and confirmed.

Scrutineers.

Mr. H. M. Ridge and Mr. G. Shaw Scott (London) were appointed scrutineers of the ballot for the examination of the voting papers, and they subsequently announced that the following seventy candidates for membership and eight candidates for associateship had been duly elected:

Members.

Name.	Address.	Proposers.
Allison, Franklin H., jun.	The University, St. George's Square, Sheffield	C. H. Desch, T. F. Russell, W. H. Bailey.
Amberton, Richard, M.I.E.E.	61 Evelyn Gardens, London, S.W. 7	W. M. Mordey, C. A. Ablett, W. R. Lewis.
Arenal Calle, Pedro .	Altos Hornos de Vizcaya, Bilbao	V. Balanzategui, A. de Churruca, L. Barreiro.

Name.	Address.	Proposers.
Atkins, Evan Arthur .	Messrs. Rylands Bros., Ltd., Church Street, Warrington	Sir W. Peter Rylands, C. E. Bunch, L. Whyatt.
Baird, Du Bois . .	Box 303, Steubenville, Ohio, U.S.A.	J. H. Lones, J. W. Beattie, M. J. Conway.
Beesly, Gerald Spencer, B.A. (Cantab.)	The Pump House, Barnt Green, Birmingham	J. H. Aston, J. Rollason, J. A. Richards.
Brandt, Boris . .	97 Mortlake Road, Kew Gardens, Richmond, Surrey	M. Yatsevitch, N. Belaiew, C.B., F. W. Harbord, C.B.E.
Brown, T. W. . .	"Hazlewood," Nantwich Road, Wells Green, near Crewe	J. H. S. Dickenson, M. G. Booth, Cosmo Johns.
Bunch, Frederick .	Bewsey Road, Warrington	Sir W. Peter Rylands, C. E. Bunch, L. Whyatt.
Caddick, William Alphaeus	Stanley House, Cornfield Road, Middlesbrough	B. Talbot, T. Twynam, J. E. James.
Camuri, *Ing.* Ugo .	Via Duchessa Jolanda 25, Turin	G. E. Falck, E. Redaelli, G. Bagna.
Carlson, August . .	Forsbacka, Sweden	C. Benedicks, A. Westgren, J. A. Leffler.
Chance, Kenneth Macomb, M.A. (Cantab.)	Radford Manor House, near Leamington	Sir R. A. Hadfield, Bart., P. B. Brown, W. J. Dawson.
Cleeves, Frederick Robert	Messrs. G. L. Scott & Co., 69 Fleet St., London, E.C. 4	C. A. Edwards, W. W. Hughes, G. L. Scott.
Cocito, *Ing.* Mario .	Via Madama Cristina, No. 9, Turin (6), Italy	G. Ciompi, A. Piccioli, G. Bagna.
Comley, Alexander .	Beechcroft, Pedmore, near Stourbridge, Worcestershire	J. Payton, C. E. Lloyd, M.P., G. Hatton, C.B.E.
Cookson, Harold Emmanuel	C/o C. Akrill & Co., Ltd., Golds Green Foundry, West Bromwich	G. Hatton, C.B.E., O. F. Grazebrook, G. Lewis.
Corlett, William Harold	44 Kingsley Road, Garden City, Queensferry	C. Bottomley, J. W. Nickson, H. Proctor Smith.
Cotterell, W. J., M.I.Mech.E.	32 Melrose Avenue, Cricklewood, London, N.W. 2	E. P. Taudevin, F. Clements, P. B. Henshaw.
Davis, J., M.Inst.C.E.	110 Victoria Street, London, S.W. 1	Sir Wm. Ellis, G.B.E., W. H. Hatfield, A. Matthews.
Deeley, Richard Bauner, B.Sc., A.R.S.M.	Preston Lodge, 5 Hampton Road, Twickenham	H. C. H. Carpenter, W. H. Merrett, W. H. Dearden.
Dockray, Thomas, B.Met.	Seneca Iron & Steel Co., Buffalo, N.Y., U.S.A.	C. H. Desch, J. G. Pearce, T. F. Russell
Duffield, Frederick Lindley	Harboro' Rocks, Brassington, near Wirksworth, Derbyshire	R. C. V. Whitfield, Sir F. Mills, Bart., L. C. Harvey.

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Freeman, Harry Brooke, A.R.S.M., D.I.C.	"Overstone," Chester Road, Shotton, Chester	H. C. H. Carpenter, G. D. Bengough, W. H. Merrett.
Gandarias, Pedro .	Alameda de Urquijo 2, Bilbao, Spain	J. Chirapozu, I. de Sojo, L. Barreiro.
Göransson, Karl Anders Fredrik	Sandviken, Sweden	E. F. Lang.
Gustafsson, Emil Gustaf	Danderydsgatan 22, Stockholm	Sir F. Mills, Bart., A. Hammarberg, A. Sjögren.
Habershon, Alfred Rix	Holmes Mills, Rotherham	H. Brearley, F. Atkinson, J. H. G. Monypenny.
Hall, Sydney Ernest .	Box 48, Vereeniging, Transvaal, South Africa	G. U. Noden, W. Scott, T. M. Pugsley.
Hamilton, Winfield C.	American Steel Foundries, Granite City, Ill., U.S.A.	J. A. Mathews, R. A. Bull, O. L. Pringle.
Heath, Oliver William	C/o Jno. Hy. Andrew & Co., Ltd., Toledo Steel Works, Sheffield	H. A. Potts, T. Swinden, E. W. Jackson.
Hume-Rothery, Wm., M.A. (Oxon.)	Mendip House, Headington Hill, Oxford	H. C. H. Carpenter, C. F. Elam, G. D. Bengough.
Ibarrola Polanco, Luis	Altos Hornos de Vizcaya, Bilbao	V. Balanzategui, A. de Churruca, L. Barreiro.
Inamullah, Syed .	Waterworks, Gaya, E.I.R., India	L. Singh.
Jackson, Captain Henry Humphrey, M.C., J.P.	Ankerbold, Tupton, Chesterfield	D. Rushworth, G. C. Bond, G. M. Jackson.
Johansson, Professor K. Arvid	Djursholm, Sweden	C. Benedicks, A. Westgren, J. A. Leffler.
Jones, David Gordon .	Bryn Amlwg House, Dunvant, Glamorganshire	C. A. Edwards, P. M. Macnair, A. L. Norbury.
Jones, Stephen Henry .	202 Godinton Road, Ashford, Kent	A. C. Walber, J. H. Doncaster, T. Peirse.
Kriegsheim, H. . .	President, Permutit Co., 440 Fourth Avenue, New York, U.S.A.	G. Shaw Scott, W. Rosenhain, D. Hanson.
Laine, John, B.Sc. (Eng.), Assoc.M.I. Mech.E.	110 Bewsey Road, Warrington	Sir E. Peter Rylands, C. E. Bunch, L. Whyatt.
Lemmy, Raymond .	C/o *Engineering*, 35 & 36 Bedford Street, Strand, London, W.C. 2	E. Schneider, Sir R. A. Hadfield, Bart., W. Rosenhain.
MacIntosh, James Rae, B.Sc., A.M.Inst.C.E.	The English Electric Co., Ltd., Central House, New Street, Birmingham	A. Hutchinson, R. H. A. Coulson, C. Pease.

Name.	Address.	Proposers.
Martin, William R., B.Sc.	Amercian Steel Foundries, 410 North Michigan Avenue, Chicago, Ill., U.S.A.	Sir Wm. Ellis, G.B.E., W. H. Hatfield, A. L. Curtis.
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Metcalf, Neil, B.Sc. (Met.)	Lynton, Prestwich Park, Prestwich, Manchester	Sir F. Mills, Bart., F. P. Hann, R. Graham.
Milling, Henry Robert, M.A.	Peter Stubs, Ltd., Warrington	A. S. Pye-Smith, F. A. Hurst, I. S. Osborn.
Misángyi, *Dr. techn.* William	Müegyetem 1, Budapest, Hungary	G. Shaw Scott, Prof. T. Turner, T. H. Turner.
Mukerji, Mrigendra Nath, B.Sc.	81 Upper Hanover Street, Sheffield	C. H. Desch, T. F. Russell, P. B. Henshaw.
Parsons, William Horace	34 Rooth Street, Wood Green, Wednesbury	G. Hatton, C.B.E., J. W. Trowsdale, H. A. Davies.
Peat, Charles	The National Federation of Iron and Steel Manufacturers, Caxton House (East), London, S.W. 1	Sir F. Mills, Bart., G. Hatton, C.B.E., E. H. Saniter.
Perrett, Laurence Arthur Steel	225 Neath Road, Briton Ferry, Glamorganshire	J. S. Lewis, R. P. Bevan, T. Crosby.
Pfeil, Leonard Bessemer, M.Sc., A.R.S.M.	University College, Swansea	H. C. H. Carpenter, C. A. Edwards, P. B. Brown.
Pickering, William Brown	52 Riverdale Road, Sheffield	P. B. Brown, J. P. Crosbie, W. J. Dawson.
Prashad, Madho	Inspector in Charge Workship Construction E.I. Railway, Tundla, United Provinces, India	F. W. Harbord, C.B.E., Fred Mills, Thomas Turner.
Raine, Alfred Johnson	"Darien," Stocksfield-on-Tyne	J. McGregor, H. C. Waterston, G. Raine.
Raine, James Edmundson	"Byethorne," Mitchell Avenue, Newcastle-upon-Tyne	J. McGregor, H. C. Waterston, G. Raine.
Salado, Jose Perez	Altos Hornos de Vizcaya, Bilbao	V. Balanzategui, A. de Churruca, L. Barreiro.
Sen, Prafulla Kumai, B.Sc.	Government Test House, Alipur, Calcutta (Bengal), India	A. Blagden, N. N. Ghosh, P. N. Day.
Senior, Edward Walters	Geo. Senior & Sons, Ltd., Ponds Forge, Sheffield	Sir A. Balfour, K.B.E., W. Clark, C. E. Siddall.
Smith, Sydney, M.I.Mech.E.	Wellman Seaver Rolling Mill Co., Ltd., 36–38 Kingsway, London, W.C. 2	J. Smith, A. V. Kemp, H. C. Wood.
Steel, Ronald	Wilsic Hall, Doncaster, Yorkshire	L. Barlow-Massicks, A. Blackmore, E. H. Saniter.
Talbot, Benjamin Chetwynd	Cross Bank Hill, Hurworth, Darlington	B. Talbot, T. Twynam, J. E. James.

NAME.	ADDRESS.	PROPOSERS.
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Tonge, John	P.O. Box 82, Vereeniging, Transvaal, South Africa	G. U. Noden, T. M. Pugsley, W. Scott.
Tornblad, Jakob Teodor	75 Victoria Street, London, S.W. 1	S. T. Garson, J. H. Harrison, W. G. Harrison.
Watson, Ernest Ansley, M.Sc.	2 St. Andrew's Road, Coventry	J. F. Kayser, T. Swinden, G. R. Bolsover.
Wilkinson Willie Horner, F.C.S.	15 Viola Terrace, Union Road, Liversedge, Yorkshire	F. Smith, E. Smith, jun., T. Baker.
Wolff, *Lieut.-Col.*, M. A., O.B.E.	10 Harborne Road, Edgbaston, Birmingham	J. H. Aston, J. Rollason, J. A. Richards.
Young, Wm. Arthur	42 Cannon Street, London, E.C. 4	G. V. Morgan, L. Pendred, W. R. Makepeace.

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Buckingham, Frederick Arthur Thomas	114 Richmond Road, Gillingham, Kent	F. W. Harbord, C.B.E., Sir F. Mills, Bart., H. C. H. Carpenter.
Cary, Charles, W. E., B.Sc.	Beverley, Hargate Drive, Hale, Cheshire	F. C. Thompson, H. O'Neill, W. E. W. Millington.
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Pearson, Thomas Felix	24 St. Andrew's Street, Netherton, Dudley, Worcestershire	T. H. Turner, J. S. Hollings, M. L. Simpson.
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Slater, Ian Griffith, B.Sc. (Hons.)	Woodsfield, Newland, Malvern, Worcestershire	T. Turner, T. H. Turner, E. W. Fell.
Woodward Cyril Sidney	45 Bidston Road, Birkenhead	C.O. Bannister, G. Varley, J. Craig, C.B.E.

ANNUAL REPORT AND STATEMENT OF ACCOUNTS.

The PRESIDENT, in suggesting that the Annual Report for the year 1925 should be taken as read, said he had to announce that Mr. Illtyd Williams, who had been the Honorary Treasurer of the Institute for a great number of years, found it impossible to continue to discharge that duty. The Council had accepted

Mr. Williams' resignation with very great reluctance, and had appointed Professor Carpenter, Member of Council, to be Honorary Treasurer in his place. He called upon Professor Carpenter to make a statement.

Professor CARPENTER then presented the following statement on behalf of Mr. Illtyd Williams, who was unavoidably prevented from attending:

Perhaps the most unfortunate feature of the whole account is the fact that the entrance fees are £75 lower than in 1924. The annual subscriptions are £40 less, which, in view of the drop in the entrance fees, is better than might naturally have been expected, the situation having been to some extent remedied by the collection of a good amount of arrears. The reduced income from subscriptions is, however, more than compensated for by the increase of Journal sales, which are expanding very satisfactorily. The total receipts stand at about £116 lower than in 1924; but this is only due to the fact that in that year there was the windfall of the surplus on the Italian Meeting Fund, otherwise the ordinary income would have been slightly higher in 1925. Turning to the expenditure side, the Journal publishing expenses have unfortunately risen by £260, due to the increase in the number of papers, and particularly to the much larger number of Plates than that published in 1924. Finally, the telephone charges have risen, for the reason that a new extension has been installed in the library, which has proved a great advantage. Turning to the balance-sheet, the Auditors have written in the market value of the investments as at December 31, 1925, and recommend the publication of the figures. It will be seen that the General Fund of the Institute shows a depreciation of over £5000.

This being the last occasion upon which I shall have the privilege of presenting the accounts, I desire to express my sense of the honour conferred upon me ten years ago when I was appointed to the treasurership. It has been a pleasure to render such small services as I have been capable of, but my task has been made light by the ever-ready advice of all Members of Council, and the great help which I have always received from the Secretary, Mr. Lloyd, and the other members of the Staff.

The President then announced to the meeting that Mr. Williams, in recognition of the honour of his election as Honorary Treasurer, had very generously promised a gift to the Institute of £3000 $3\frac{1}{2}$ per cent. Conversion Loan Stock, the income of which was to be devoted to the awarding of a prize or prizes for the encouragement of the preparation of papers on practical subjects, and it was his wish that the prize should be known as "The Williams Prize," in commemoration of his father's name, who had given many years' service to the Institute and was one of its Past-Presidents. The President hoped that Mr. Williams' generous action would not only be acceptable but would be productive of good work by the younger members of the Institute in the future. He felt sure that it would be the members' pleasure that an appropriate vote of thanks should now be expressed to Mr. Williams, not only in appreciation of his work as Honorary Treasurer for a long period of years, but for his munificent gift to the Institute on the occasion of his retirement.

The President's vote of thanks to Mr. Williams was then put to the meeting and carried amid very hearty applause.

On the motion of the President, the Balance Sheet and Statement of Accounts (see pp. 19-22) were unanimously adopted.

REPORT OF COUNCIL.

The Council of the Iron and Steel Institute have much pleasure in submitting for the approval of the members at this, the Fifty-seventh Annual General Meeting, their Report on the proceedings and work of the Institute during the year 1925.

Roll of the Institute.

During the past year sixty-five new members and eight associates were elected, and six associates were transferred to membership. The total membership of the Institute on the register on December 31, 1925, was therefore as follows :

Patron	1
Honorary Members	11
Life Members	78
Ordinary Members	1899
Associates	33
Total	2022

Fifty-nine members and two associates resigned their membership during the year, and the names of thirty-seven members were removed from the register owing to the non-payment of their subscriptions.

The Council deeply regret to have had to record the deaths of the following thirty-six members of the Institute which occurred during the year :

Backert, A. O. (Cleveland, U.S.A.)	April 24.
Barnbrook, J. H. (Glasgow)	March 27.
Bates, H. (Manchester)	October 17.
Bleckly, H. S. (Hale, Cheshire)	February 20.
Brinell, Dr. J. A. (Nassjo, Sweden) (Life Member)	November 17.
Campbell, Professor E. D. (Ann Arbor, U.S.A.)	September 18.
Cleeves, F. (London)	January 10.
Coppée, Baron E. (Brussels)	June 24.
Crabtree, Professor F. (Pittsburgh, U.S.A.)	February 14.
Dempster, R. (Hartford, Cheshire)	May 17.
Fellows, R. (Wolverhampton)	June.
Firth, T. H. (Sheffield)	July 16.
Haynes, Elwood (Kokomo, U.S.A.)	April 13.
Henderson, J. M. (Aberdeen) (Life Member)	February 19.
Hollings, W. W. (Brymbo, nr. Wrexham)	June 17.

Hughes, R. T. (Middlesbrough)	April 5.
Jackson, W. U. (Wolverhampton)	July 19.
Jenkins, James G. (Cambuslang)	February 8.
Jones, J. C. (Redcar)	February 16.
Latinis, V. (Brussels)	July 3.
Leith of Fyvie, Lord (Fyvie, Aberdeenshire)	November 14.
Lester, I. E. (Birmingham)	November 27.
Livesey, James (London)	February 3.
McConway, William (Pittsburgh, U.S.A.)	July 28.
Reynolds, G. B. (Trinidad)	March.
Rogerson, J. E. (Durham)	March 23.
Sankey, Captain H. Riall, R.E., C.B., C.B.E. (London)	October 3.
Service, A. G. (Glasgow)	January.
Swan, E. W. (Middlesbrough)	March 9.
Tamm, Baron Gustaf (Stockholm) (Hon. Member)	June 25.
Thompson, J. W. (Manchester)	March 17.
Tisdall, A. D. (London)	July 12.
Torbock, J. (Penrith)	April.
Trotz, J. O. E. (Ronneby, Sweden)	July.
Wallwork, R. (Manchester)	January 14.
Widdowson, J. H. (Manchester)	November 25.

The deaths of the following four members took place prior to 1925, but were not reported to the Council until that year :

Diedrichs, G. H. (Stockholm)	1924.
Harrison, G. H. (Hagley)	September 1924.
Schwab, C. (Sheffield)	June 1924.
Williamson, S. W. (Glasgow)	July 1924.

The Council specially wish to place on record their sense of the great loss to the Institute, and to scientific metallurgy in general, incurred through the death of Dr. J. A. Brinell, the world-famous Swedish Metallurgical Engineer, and Bessemer Medallist of the Institute. They also have to deplore the loss of other distinguished members and faithful supporters in the persons of Baron Evence Coppée, Captain H. Riall Sankey, R.E., C.B., C.B.E., and Mr. Isaac E. Lester. The last named was a member of the Executive Committee of the recent Birmingham Meeting, and took an active part in organising the arrangements for the reception and guidance of the members.

Honours Conferred on Members of the Institute.

The Council tender their most hearty congratulations to several members of the Institute upon whom appointments of honour and distinction have been conferred during the year.

The President of the French Republic has been pleased to confer the Insignia of Officer of the Legion of Honour upon Sir Robert A. Hadfield, Bart. (Past-President).

Sir William Ellis, G.B.E., D.Eng. (Past-President), has been elected President of the Institution of Civil Engineers.

Mr. G. E. Falck has been made Cavaliere Ufficiale of the Order of St. Maurice and St. Lazarus. Mr. C. P. Sandberg has been created a Commander of the Order of the White Elephant of Siam, while Mr. N. P. Sandberg and Mr. O. F. A. Sandberg have each received the Order of the Crown of Siam. Mr. Luis Barreiro has been appointed Consul of the Dominican Republic at Bilbao.

Dr. R. Moldenke is to be congratulated upon being the first recipient of the Joseph S. Seaman Gold Medal of the American Foundrymen's Association. Mr. J. de Lazurtegui has been made an Honorary Member of the American Academy of Political and Social Science; Dr. D. H. Ingall has obtained the degree of D.Sc. at the University of Birmingham; and Dr. Constance F. Elam has been equally successful in Metallurgy at the University of London. The Honorary degree of Doctor of Commercial Science has been conferred on Judge E. H. Gary by New York University.

Finance.

The Statement of Accounts for the year 1925, which has been duly audited and certified by Messrs. W. B. Keen & Co., the Institute auditors, accompanies this report, and is presented for approval by Mr. Illtyd Williams, the Honorary Treasurer. At the same time the Council much regret to have to announce that Mr. Williams has since found himself compelled to resign the Hon. Treasurership, which office he has held for the last ten years. During this period he has rendered invaluable service to the Institute, and his retirement is greatly regretted by all.

The income of the year under review, exclusive of the Carnegie Scholarship Fund and of the interest received from the Special Purposes Fund, was £7952, and the expenditure for the year was £8084. The comparative figures for income and expenditure for the last five years are shown herewith:

	Income.	Expenditure.
	£	£
1920	8419	7622
1921	8349	6866
1922	7964	7939
1923	8095	8012
1924	8068	7568

Meetings.

The Annual Meeting of the Institute was held in the hall of the Institution of Civil Engineers, by kind permission of the Council of that body, on Thursday and Friday, May 7 and 8, 1925, the chair being taken by the President, Sir Frederick Mills, Bart., D.L., M.Inst.C.E.

The Annual Dinner was held at the Hotel Cecil on the evening of Thursday, May 7, and was attended by some 250 members and guests. Speeches were delivered by Sir William Ellis, G.B.E., D.Eng., Past-President; Sir Philip Cunliffe-Lister, K.B.E., President of the Board of Trade; The Right Hon. John Hodge; the President; Sir W. Peter Rylands, Vice-President; and Mr. Evan Williams, President of the Mining Association of Great Britain.

The Autumn Meeting of the Institute was held at Birmingham on September 9 and 10, and was attended by nearly 400 members and their ladies. The visitors were entertained to lunch on Wednesday, September 9, by the Local Reception Committee, and the same evening a Reception and Dance were given in their honour in the Council House by the Lord Mayor of Birmingham and the Lady Mayoress. On the evening of Thursday, September 10, a Conversazione was held at the University Buildings, Edgbaston, when the Vice-Chancellor, Sir Gilbert Barling, Bart., and Miss Barling, Principal C. Grant Robertson, M.A., C.V.O., and Professor Turner, Dean of the Faculty of Science, received the guests. On the afternoons of both those days visits were made to sixteen works in Birmingham and the neighbourhood, where the members of the parties saw much of interest and were most hospitably entertained by the directors and members of the various staffs. On Friday, September 11, a large number of the members and their ladies made a very enjoyable tour of several places of noted interest, including Kenilworth Castle, Guy's Cliffe, Warwick, and Stratford-on-Avon. The success of the meeting was very largely due to the careful forethought and excellent arrangements of the Local Reception Committee, and the results of their labours were very much appreciated.

Thirty-two papers were contributed to the Proceedings of the Institute during the year. Of these papers fourteen were presented at the Annual Meeting and eighteen at the Birmingham Meeting, and all of them, together with discussions and correspondence, have been reprinted in the Journal. The following is a complete list:

Aitchison, L., and L. W. Johnson—"The Effect of Grain upon the Fatigue Strength of Steels."

Andrew, J. H., and R. Higgins—"The Dilatation of Cast-Irons during Repeated Heating and Cooling."

Becker, M. L.—"Equilibrium at High Temperatures in the Iron-Carbon-Silicon System."

Campbell, D. F.—"A High-Frequency Induction Furnace."

Campbell, E. D., and J. F. Ross—"The Chromium-Iron Equilibrium in Carbides recovered from Annealed 2·23 per Cent. Chrome Steels."

Eckermann, H. von—"A Method for Reducing the Percentage of Phosphorus in Swedish Iron by Diminishing the Phosphorus in the Charcoal."

Edwards, C. A., and L. B. Pfeil—"The Tensile Properties of Single Iron Crystals and the Influence of Crystal Size upon the Tensile Properties of Iron."

Elam, C. F.—"The Orientation of Crystals produced by Heating Strained Iron."

Enlund, B. D.—"On the Structure of Quenched Carbon Steels."

Flodin, H.—"A New Direct Process for the Manufacture of Steel."

Friend, J. Newton, and W. E. Thorneycroft—"Ancient Iron from Richborough and Folkestone."

Gray, G. Watson, and C. D. Garbutt—"The Estimation of Phosphorus in the Presence of Vanadium."

Greaves, R. H., and J. A. Jones—"Temper-Brittleness of Steel; Susceptibility to Temper-Brittleness in Relation to Chemical Composition."

Greaves, R. H., and J. A. Jones—"The Effect of Temperature on the Behaviour of Iron and Steel in the Notched-Bar Impact Test."

Grenet, L.—"Notes on the Iron-Nickel and Iron-Cobalt Equilibrium Diagrams."

Griffiths, W. T.—"Note on Nitrogen as a Possible Factor in Temper-Brittleness."

Hand, T. W.—"Progress in British Rolling-Mill Practice."

Honda, K.—"On the A2 Line in the Equilibrium Diagram of the Iron-Carbon System."

Hultgren, A.—"Flakes or Hair-Cracks in Chromium Steel, with a Discussion on Shattered Zones and Transverse Fissures in Rails."

Ingall, D. H., and H. Field—"Peeling in White-Heart Malleable."

Jevons, J. Dudley—"Strain Detection in Mild Steel by Special Etching."

Kamura, H.—"Reduction of Ferric Oxide and Iron Ores by Hydrogen."

Keenan, J. L.—"Notes on Blast-Furnace Practice in India, with Special Reference to Economy in Coke Consumption."

Lobley, A. Glynne, and C. L. Betts—"The Influence of Gases at High Temperatures upon Iron, with Special Reference to the Formation of Blowholes."

Martin, W. R.—"The Davis Steel Wheel and its Manufacture in England."

Mathews, J. A.—"Retained Austenite."

Partridge, J. H.—"The Magnetic and Electrical Properties of Cast-Iron."

Sauveur, A., and V. N. Krivobok—"Dendritic Segregation in Iron-Carbon Alloys."

Sauveur, A., and D. C. Lee—"The Influence of Strain and of Heat on the Hardness of Iron and Steel."

Smith, R. L., and G. E. Sandland—"Some Notes on the Use of a Diamond Pyramid for Hardness Testing."

Turner, T. Henry, and J. Dudley Jevons—"The Detection of Strain in Mild Steels."

Whiteley, J. H.—"Observations on Martensite and Troostite."

Volume XIV. of the Carnegie Scholarship Memoirs was published in August 1925, and contained the following reports:

CURTIS, A. L.—"Steel Moulding Sands and their Behaviour under High Temperatures."

REED, E. L.—"An Investigation of the Properties of Iron-Carbon Alloys. (A) Melted in Vacuum. (B) Melted in Air."

TAYLOR, E. R.—"The Effect of Sulphur on the Mechanical Properties of White-Heart Malleable Cast-Iron."

WHITELEY, J. H., and A. F. HALLIMOND—"The Reactions of Plain Carbon Steels with Nitric Acid."

JOINT MEETING.

At the invitation of the Faraday Society, a joint meeting was held on June 8 at the Institution of Civil Engineers. Sir Robert Hadfield, Bart., was in the chair, and the following nine papers bearing on the subject, "The Physical Chemistry of Steel-Making Processes," were presented:

COLCLOUGH, T. P.—"A Study of Reactions in the Basic Open-Hearth Furnace."

FEILD, A. L.—"Physico-Chemical Phenomena from Melt to Ingot."

FERGUSON, J. B.—"Equilibria in Systems involving Ferrous Oxide."

HADFIELD, Sir ROBERT—"Physical Chemistry in Steel Making."

McCANCE, A.—"Balanced Reactions in Steel Manufacture."

MACNAIR, P. M.—"Slag-Reactions."

REES, W. J.—"The Micro-Examination of Steel-Making Refractories."

SISCO, F. T.—"The Chemical Reactions of the Basic Electric Process."

WHITELEY, J. H.—"The Function of Ferric Oxide in Acid and Basic Open-Hearth Slags."

A report of the proceedings, available at a reduced rate to members of this Institute, has been prepared and published by the Faraday Society.

BESSEMER MEDAL.

The Bessemer Gold Medal for the year 1925 was awarded by the Council of the Institute to Professor Thomas Turner, M.Sc., of Birmingham University, in recognition of his distinguished services in the advancement of the science of the metallurgy of iron and steel.

ANDREW CARNEGIE RESEARCH SCHOLARSHIPS.

On the recommendation of the Carnegie Scholarship Committee, grants were made by the Council during the year to the following candidates:

W. CRAFTS (Reading, U.S.A.), £100, to carry out a research on the production of carbonless chromium by the method of leaching and electrolytic deposition of chromium from chromite.

W. H. Dearden (London), £100, to study the specific heat of iron below 400° C.

T. H. Turner and E. W. Fell (Birmingham), £100 jointly, to investigate methods of detection and the nature of permanent deformation or strain in steels.

R. Higgins (Glasgow), £100, to study the volume changes in cast-iron brought about by repeated heating and cooling.

H. O'Neill (Manchester), £100, to study the nature of hardness in relation to cold-working and machining properties of metals.

J. H. Partridge (Birmingham), £50, to investigate the electric and magnetic properties of cast-iron.

L. B. Pfeil (Swansea), £100, for a study of the growth of large crystals by annealing strained iron, including the properties of such crystals.

It was also recommended that, the Committee having satisfied itself as to the good progress of the research work undertaken by the four following investigators, to whom grants had previously been awarded, further grants be made to them of the amounts specified :

C. H. Adamson and G. S. Bell (Sheffield and Lincoln), £50, to continue their research on transverse cast-iron test-bars.

D. W. Berlin (Rasunda, Sweden), £50, to study the specific gravity of liquid iron.

A. L. Curtis (Chatteris, Cambs.), £50, to assist his investigations on steel moulding sands.

E. R. Taylor (Birmingham), £50, to continue his study of the effect of manganese and sulphur on the properties of malleable cast-iron.

Publications.

During 1925 the Institute published two volumes of the Journal, containing together nearly 1300 pages, a volume of Carnegie Scholarship Memoirs of 186 pages, and the usual List of Members (170 pages).

Library and Offices.

Among the new books to be found on the shelves of the Library are included the following donations from authors, publishers, and others, and the Council take this opportunity of extending their sincere thanks to the donors for their generosity :

"The Chemical Coloring of Metals and Allied Processes," by S. Field and S. R. Bonney ; "Molybdenum, Cerium, and Related Alloy

Steels," by H. W. Gillett and E. L. Mack: "Determination of Dimensions: Blast-Furnaces and Open-Hearth Furnaces," by M. Pavloff, printed in Russian; "Cadmium: its Metallurgy, Properties, and Uses," by N. F. Budgen; "Metallurgy of Steel," by M. M. Karnaukhov, in 2 vols., printed in Russian; "The Metallurgy of Aluminium and Aluminium Alloys," by R. J. Anderson; "Trade Stability, and How to Obtain it," by Sir Charles W. Macara, Bart.; "A Course of Metallurgy for Engineers," by F. C. Thompson; "L'Industrie des Produits Chimiques et ses Travailleurs," by A. Matagrin; "Metallographie," Vol. II., Part 2, No. 6, by W. Guertler; "Bau und Betrieb moderner Konverterstahlwerke und Kleinbessemereien," by H. Hermanns; "Wire-Drawing and the Cold-Working of Steel," by A. T. Adam; "Jernkontorets Samlingar av Svenska Bergshistoriska Bilder," by S. Rönnow; "Cementacja Borem (Naborowywanie) Zelaza, Niklu I Kobaltu," by I. Feszczenko-Czopiwski; "Jamsetji Nusserwanji Tata: a Chronicle of his Life," by F. R. Harris; "Manganese Ore, with Special Reference to Georgian Ore," by D. Zereteli; "Anniversary Volume dedicated to Professor Hantaro Nagaoka"; "'Hütte': des Ingenieurs Taschenbuch," 25th edition, Vol. I.; "Anuario de Mineria, Metalurgia, Electricidad y Demas Industrias de España," published by Revista Minera; "Physical Metallography," by E. Heyn; "Metallurgy and its Influence on Modern Progress, with a Survey of Education and Research," by Sir Robert Hadfield, Bart.

Among the books that have been purchased by the Institute the following may be mentioned: "The Fatigue of Metals," by H. J. Gough; "English Industries of the Middle Ages," by L. F. Salzman; "The Science of Metals," by Z. Jeffries and R. S. Archer; "Sands and Crushed Rocks," in two volumes, by A. B. Searle; "Manufacture and Uses of Alloy Steels," by H. D. Hibbard; "Elements of Metallography," by R. Ruer; "Les Fours à Coke: étude théorique et pratique," by E. and L. Lecocq; "Allgemeines Profilverzeichnis der Deutschen Eisenwalzwerke," 3rd edition, by H. Pila; "Die Gaserzeuger: Handbuch der Gaserei mit und ohne Nebenproduktengewinnung," by H. R. Trenkler; "Die Physikalischen und Chemischen Grundlagen des Eisenhüttenwesens," by W. Mathesius; "Die Theorie der Eisenkohlenstoff-Legierungen," by E. Heyn; "Die Elektrostahlöfen," by E. F. Russ; "Notes on Iron and Steel," by R. K. Bagnall-Wild; "Proceedings of the International Scientific Congress, Liége, 1922," in nine volumes; "Transactions of the First World Power Conference, London, 1924," in four volumes; "Proceedings of the Empire Mining and Metallurgical Congress, London, 1924," in five volumes;

"Fluxes and Slags in Metal Melting and Working," A General Discussion before the Faraday Society; "Fuel: Solid, Liquid, and Gaseous," 3rd edition, by J. S. S. Brame; "Pattern Making," 5th edition, by J. G. Horner; "The Conversion of Coal into Oils," by F. Fischer; "Handbook of the Geology of Ireland," by G. A. J. Cole and T. Hallissy; "Heat Treating: its Principles and Applications," by C. H. Fulton, H. M. Henton, and J. H. Knapp; "Erz- und Minerallagerstätten des Schwarzwaldes," by M. Henglein; "Die Edelstähle, ihre metallurgischen Grundlagen," by F. Rapatz; "A Text-Book of Metallography," by G. Tammann.

Great and growing appreciation by the members is being shown in the development of the Library services. By the adoption of the practice of sending out books on loan, a distinct need among the members has been met to a large extent. The usefulness of the scheme has been increased as far as possible by the regular acquisition of all the more important new works on metallurgical and kindred subjects appearing each half-year, and by regular subscription to the principal scientific and technical periodicals of all countries.

The arrangements for dealing promptly with inquiries on any technical subject associated with the work of the Institute have continued to work satisfactorily.

On June 25 Mr. L. P. Sidney resigned the position of Assistant Secretary, which office he had held for twenty-one years, and the Council have appointed Mr. Alan E. Chattin, B.Sc., to fill the position thus rendered vacant.

Appointment of Representatives.

The President continues to represent the Institute on the General Committee of the Royal Society for administering Government Grants for Scientific Investigations. Sir Robert Hadfield, Bart., and Mr. F. W. Harbord, C.B.E., represent the Institute on the Board of the National Physical Laboratory, and Sir Hugh Bell, Bart., performs a like office on the Board of Governors of the Imperial College of Science and Technology.

The Institute representatives on the British Engineering Standards Association are Dr. A. Cooper, Mr. M. Mannaberg, and Mr. B. Talbot; on the Sectional Committee of that Association for the Standardisation of Galvanised Sheets, Mr. C. Dorman; on the Sub-Committee for Cast-Iron, working under the direction of the Sectional Aircraft Committee,

Mr. H. J. Yates and Dr. W. H. Hatfield ; on the Sectional Committee on Cast-Iron, Mr. H. B. Toy ; on the Technical Committee of Motor Industries, Mr. J. H. S. Dickenson ; and on the Sectional Committee for Chemical Engineering, Mr. F. W. Harbord, C.B.E.

Mr. F. Clements is the Institute representative on Panel D, on Gas-Producer Trials of the Institution of Civil Engineers. Professor T. Turner is the Institute's Delegate to the British Cast Iron Research Association. Sir R. Hadfield and Mr. Harbord represent the Institute on the Council of the British Refractories Research Association, and Mr. Harbord represents the Institute on the Alloys of Iron Research Committee, on the Advisory Board of the Royal School of Mines, and, with Sir Robert Hadfield, Bart., on the Federal Council for Pure and Applied Chemistry. On the Committee on the Improvement and Development of Basic Slag, formed by the Ministry of Agriculture and Fisheries, the Institute is represented by Dr. A. Cooper, Mr. M. Mannaberg, Mr. G. Hatton, C.B.E., and Mr. B. Talbot ; on the Grey and Malleable Iron Research Committee of the Department of Scientific and Industrial Research by Professor T. Turner; on the Technical Committee of Lloyd's Register of Shipping by Lord Invernairn and Mr. W. Simons ; and on the Board of Governors of the School of Metalliferous Mining (Cornwall) by Professor H. Louis.

Sir Robert Hadfield, Bart., represents the Institute on the British Association Fuel Economy Committee, on the Court of Sheffield University, and on the Home Committee for the University of Hong Kong ; while Sir W. Peter Rylands acts similarly on the Court of the University of Liverpool.

Changes on the Council.

At the Annual Meeting in May 1925, Sir Frederick Mills, Bart., D.L., was elected President of the Institute ; Professor Louis was elected a Vice-President, and Mr. James Henderson a Member of Council, to fill the vacancies thus created. At the Birmingham Meeting the Council unanimously nominated Sir W. Peter Rylands, Vice-President, to succeed Sir Frederick Mills, Bart., as President.

Professor J. O. Arnold has been elected an Honorary Vice-President, and Mr. Arthur Dorman was chosen to fill the vacant seat on the Council.

In accordance with Byelaw 10, the names of the following Vice-Presidents and Members of Council were announced at the Autumn Meeting as being due to retire at the Annual Meeting, 1926 :

Vice-Presidents—Lord Airedale; Mr. B. Talbot; Mr. W. R. Lysaght.

Members of Council—Professor T. Turner; Mr. E. H. Saniter; Mr. John Craig; The Hon. R. D. Kitson, D.S.O.; and Professor H. C. H. Carpenter.

No other members having been nominated up to one month previous to the Annual Meeting, the retiring members, in accordance with the announcement made at the Autumn Meeting, are presented for re-election.

THE IRON AND STEEL INSTITUTE.

BALANCE SHEET, DECEMBER 31, 1925.

LIABILITIES.

Sundry Creditors :—			
Journal Printing and Publishing		£789 12 11	
Journal Postage		62 2 8	
Library Books and Binding		11 7 3	
Office Rent, &c.		268 19 3	
Autumn Meeting		4 11 8	
Stationery, Printing, and Postage		18 13 9	
			£1,155 7 6
Entrance Fees and Subscriptions in advance			68 19 6
Journal Sales, Amount received in advance			69 3 6
Life Compositions Fund :—			
As at 1st January 1925		2,990 4 3	
Add Fee received during year		31 10 0	
			3,021 14 3
Carnegie Scholarship Fund :—			
Sundry Creditors—			
Printing Memoirs	£1 9 3		
Grants due 1925	237 10 0		
Amount due to Institute's General Fund ...	81 8 1		
		£320 7 4	
Amount of Fund		21,241 5 6	
Add Accumulated Surplus Income :—			
As at 1st January 1925	£3,551 4 0		
Less Excess of Expenditure over Income to 31st December 1925	281 15 2		
		3,269 8 10	
			24,831 1 8
Special Purposes Fund :—			
Capital Account, representing subscriptions received 1919–20 invested *per contra*		9,451 0 0	
Income and Expenditure Account :—			
Balance at 1st January 1925	£812 12 11		
Add Excess of Income over Expenditure for the year ended 31st December 1925	10 15 10		
		823 8 9	
			10,274 8 9
Iron and Steel Institute Capital Account :—			
As per last Balance Sheet		£15,839 12 11	
Less Excess of Expenditure over Income for the year		132 2 5	
			15,707 10 6
			£55,128 5 8

ASSETS.

Sundry Debtors :—			
Entrance Fees and Subscriptions in arrear, since received		£116 0 6	
Journal Sales, since received		394 15 5	
Interest on Investments		240 4 2	
Amount due from Carnegie Scholarship Fund...		81 8 1	
Telephone Deposit		1 0 0	
Miscellaneous		9 8 0	
			£842 16 2
Journal Paper—In Stock			27 3 4
Investments, at cost, as per Schedules :—			
* General Fund		15,562 12 5	
* Life Compositions Fund		2,990 4 3	
			18,552 16 8
(* The Market Value of these Securities at 31st December 1925 was £13,348 15*s.* 11*d.*)			
Cash at Bank and in Hand :—			
General Account		£251 5 0	
Life Compositions Fund		31 10 0	
Secretary's Account		313 8 8	
Cash at Office		3 15 5	
			599 19 1
Carnegie Scholarship Fund :—			
* Investments at cost, as per Schedule...		£22,146 7 10	
Interest on Investments accrued due at 31st December 1925, since received ...		388 12 6	
Cash at Bank on Deposit Account		2,296 1 4	
			24,831 1 8
(* The Market Value of these Securities at 31st December 1925 was £20,939 16*s.* 3*d.*)			
Special Purposes Fund :—			
* £12,242 19*s.* 3*d.* 4 per cent. Funding Stock, 1960–90		£9,512 7 5	
Cash at Bank :—			
Current Account	£109 6 4		
Deposit Account	652 15 0		
		762 1 4	
			10,274 8 9
(* The Market Value of this Security at 31st December 1925 was £10,406 10*s.* 4*d.*)			
			£55,128 5 8

GENERAL FUND.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED DECEMBER 31, 1925.

INCOME.

To Entrance Fees		£147 0 0
,, Annual Subscriptions :—		
Members	£5793 18 2	
Associates	44 2 0	
		5838 0 2
,, Journal Sales		1215 2 10
,, Interest on Investments :—		
General Fund, *Less* Tax	473 18 2	
Income Tax recovered	109 4 7	
		583 2 9
Life Compositions Fund, *Less* Tax	90 14 6	
Income Tax recovered	22 1 9	
		112 16 3
,, Bessemer Medal Fund :—		
Interest on Investments, *Less* Tax	£12 14 0	
Income Tax recovered	3 12 0	
		16 6 0
,, Interest on Deposit		37 1 1
,, Sale of Wastepaper		1 10 0
,, Sundry Receipts		1 6 6
		£7952 5 7
,, Excess of Expenditure over Income carried to Balance Sheet		132 2 5
		£8084 8 0

EXPENDITURE.

By Salaries (including Overtime)		£3172 10 9
,, Gratuity to late Assistant Secretary		375 0 0
,, Office Rent, Cleaning, &c....		1061 14 10
,, Library Books and Binding		140 5 6
,, Office Furniture		23 5 4
,, Autumn Meeting		236 12 1
,, Annual Meeting		137 15 6
,, Journal Publishing Expenses :—		
Printing, &c.	£1875 1 11	
Abstracts	122 6 8	
Translations	3 7 6	
Postages	112 18 9	
		2113 14 10
,, Stationery and Printing (including copies of Papers)... ...		440 5 1
,, Postage and Receipt Stamps		132 8 1
,, Travelling Expenses		24 13 7
,, Insurance		27 19 6
,, Telephone Rental and Calls		31 11 3
,, Auditor's Fees		31 10 0
,, Bessemer Medal		14 7 6
,, Compassionate Allowance		50 0 0
,, Office Disbursements and Sundry Payments		70 14 2
		£8084 8 0

ANDREW CARNEGIE RESEARCH SCHOLARSHIP FUND.

ACCOUNT OF INCOME AND EXPENDITURE FOR THE YEAR ENDED DECEMBER 31, 1925.

INCOME.

	£	s.	d.	£	s.	d.
To Interest on Investments:—						
£2250 Newcastle-upon-Tyne Electric Supply 4½ per cent. Consolidated First Mortgage Debenture Stock	£80	6	9			
£7925 London & North Eastern Railway 4 per cent. Debenture Stock...	251	12	4			
£1312 London & North Eastern Railway 4 per cent. 1st Guaranteed Stock	41	13	5			
£8750 London & North Eastern Railway 3 per cent. Debenture Stock...	208	7	2			
£2000 London Midland & Scottish Railway 4 per cent. Debenture Stock	63	10	0			
£1500 Great Western Railway 4 per cent. Debenture Stock	47	12	6			
£2560 4s. India 3 per cent. Stock	76	16	0			
£2300 India 3½ per cent. Stock	80	10	0			
£1000 5 per cent. War Stock, 1929–47 ...	39	16	0			
				£890	4	2
,, Interest on Deposit				78	7	3
,, Income Tax recovered to 5th April 1925				207	14	6
,, Excess of Expenditure over Income carried to Balance Sheet				281	15	2
				£1458	1	1

EXPENDITURE.

	£	s.	d.	£	s.	d.
By Scholarship Grants	£850	0	0			
Less Balance of 1923 and 1924 Grants lapsed...	150	0	0			
				£700	0	0
,, Printing Memoirs				614	1	1
,, Postage of Memoirs				40	0	0
,, Salaries				104	0	0
				£1458	1	1

SPECIAL PURPOSES FUND.

ACCOUNT OF INCOME AND EXPENDITURE FOR THE YEAR ENDED DECEMBER 31, 1925.

INCOME.

	£	s.	d.
To Interest on Funding Stock, *Less* Tax	£385	13	1
,, Interest on Deposit	17	10	3
,, Income Tax recovered	55	1	10
	£458	5	2

EXPENDITURE.

	£	s.	d.	£	s.	d.
By Grants:—						
Alloys Research Committee	£250	0	0			
Ramsay Memorial Laboratory	52	10	0			
British Refractories Research Association ...	25	0	0			
The Optical Convention	10	10	0			
				£338	0	0
,, Expenses of Technical Committee				109	9	4
				447	9	4
,, Excess of Income over Expenditure carried to Balance Sheet				10	15	10
				£458	5	2

INVESTMENTS ON ACCOUNT OF GENERAL FUND OF THE INSTITUTE.

	£	s.	d.
£1000 5 per cent. War Stock, 1929–47	£945	16	4
£549 19*s*. 2*d*. 3½ per cent. Conversion Stock	409	11	0
£447 Southern Railway 4 per cent. Debenture Stock	449	2	4
£1872 London & North Eastern Railway 4 per cent. Second Guaranteed Stock	2,148	13	3
£1872 London & North Eastern Railway 4 per cent. First Preference Stock	2,148	13	4
£2241 London & North Eastern Railway 4 per cent. First Guaranteed Stock	2,431	14	5
£1500 Buenos Ayres Great Southern Railway 4 per cent. Debenture Stock	1,594	12	9
£1000 Calcutta 4 per cent. Bonds, 1939	982	10	0
£800 Bombay 4 per cent. Bonds, 1939	809	0	0
£79 4*s*. 5*d*. "B" Annuity, Scinde, Punjaub, and Delhi Railway	1,999	0	7
£50 1*s*. 8*d*. "B" Annuity, Great Indian Peninsula Railway	1,267	6	0
£137 London & North Eastern Railway 3 per cent. Debenture Stock	376	12	5
	£15,562	12	5

INVESTMENTS ON ACCOUNT OF LIFE COMPOSITIONS FUND.

	£	s.	d.
£1330 London & North Eastern Railway 3 per cent. Debenture Stock	£1,254	17	6
£335 London Electric Railway 4 per cent. Perpetual Stock	304	14	11
£335 Metropolitan District Railway 4 per cent. Prior Lien Debenture Stock	333	11	2
£376 London & North Eastern Railway 4 per cent. Second Preference Stock	371	0	8
£681 13*s*. 4 per cent. Funding Loan, 1960-1990	600	0	0
£160 14*s*. 2*d*. 3½ per cent. Conversion Loan	126	0	0
	£2,990	4	3

INVESTMENT ON ACCOUNT OF SPECIAL FUND.

	£	s.	d.
£12,242 19*s*. 3*d*. 4 per cent. Funding Loan, 1960–1990	£9,512	7	5

INVESTMENTS ON ACCOUNT OF ANDREW CARNEGIE RESEARCH SCHOLARSHIP FUND.

	£	s.	d.
£2250 Newcastle-upon-Tyne Electric Supply 4½ per cent. Consolidated First Mortgage Debenture Stock	£2,261	10	0
£7925 London & North Eastern Railway 4 per cent. Debenture Stock	6,465	1	0
£1312 London & North Eastern Railway 4 per cent. First Guaranteed Stock	880	11	11
£8750 London & North Eastern Railway 3 per cent. Debenture Stock	5,611	2	8
£2000 London Midland & Scottish Railway 4 per cent. Debenture Stock	1,693	0	6
£1500 Great Western Railway 4 per cent. Debenture Stock	1,204	5	3
£2560 4*s*. India 3 per cent. Stock	1,525	3	3
£2300 India 3½ per cent. Stock	1,600	2	9
£1000 5 per cent. War Stock, 1929–1947	905	10	6
	£22,146	7	10

(Signed) ILLTYD WILLIAMS, *Hon. Treasurer*. G. C. LLOYD, *Secretary*.

I have examined the foregoing Balance Sheet and Income and Expenditure Accounts with the Books and Vouchers of the Institute, and certify them to be correct. I have also verified the Balances at the Bankers and the Securities for the Invested Funds shown above.

23 QUEEN VICTORIA STREET, LONDON, E.C. 4 : 6*th April* 1926. (Signed) W. B. KEEN, *Chartered Accountant*.

BESSEMER MEDAL FUND (Trustees: Sir HUGH BELL, Bart., Lord AIREDALE, and FRANCIS SAMUELSON, Esq.).
£400 London Midland and Scottish Railway 4 per cent. Debenture Stock.

Induction of the New President.

Sir Frederick Mills said his next duty was one which gave him very great pleasure ; it was to ask Sir Peter Rylands to take the Presidential Chair. Sir Peter Rylands was well known in the industry as Chairman of the British Iron and Steel Wire Association, he having held that position for twenty-five years. That in itself was a sufficient recommendation. He was a Director of several important iron and steel works in the country, and, curiously enough, he was also a barrister—the first barrister, he (Sir Frederick Mills) thought, to become a steel-maker. He could understand the contrary being the case, but on the present occasion it was a peculiar conjunction of occupations, and he was sure that Sir Peter's knowledge of the law would be useful in keeping the members all in order. He wished Sir Peter Rylands as happy a year of office as he himself had had.

[The Chair was then vacated by Sir Frederick Mills and was taken by Sir W. Peter Rylands.]

Sir Peter Rylands said he much esteemed the great honour which the Institute had done him in placing him in the position of its President, following in the footsteps of many most distinguished men. He could only trust that when the time arrived for him to lay down the reins of office he should have in no way allowed the dignity of the position to have been impaired by the manner of its discharge in his hands. He thanked the members very much, and asked for their loyal support during the year which lay before him—a year of undoubted difficulty.

He then asked the members to record their appreciation of the services which had been rendered to the Institute by Sir Frederick Mills during his year of office. The position of President carried with it responsibilities, and the members owed a great deal, if he might say so, to their Past-Presidents. In every regard Sir Frederick Mills had upheld the dignity of the office and had discharged his duties to the satisfaction of all the members.

The vote of thanks was then put and carried with acclamation.

Sir Frederick Mills, in reply, thanked the members very much indeed for the very kind vote they had just passed. He had to apologise to Sir Peter Rylands for having impinged upon his year of office by one month, but that had been owing to circumstances entirely beyond his control. He was sure Sir Peter would forgive him and make the best use of the time that was left to him.

Presentation of the Bessemer Gold Medal.

The President said the Institute had in their hands the pleasant duty of bestowing each year, through the munificence of Sir Henry Bessemer, a medal to some gentleman who in some way, either in particular or in general, had deserved well of the industry, and who had materially assisted in its well-being. This year the Council had selected Sir Hugh Bell as the recipient. One might perhaps be inclined to feel that the honour was somewhat belated. The name of Bell was a household word in the iron and steel industry; perhaps there was no name which was more associated with it than that of Bell. Sir Lowthian Bell might be regarded as one of the most important pioneers of the industry in the north, and Sir Lowthian himself had been the recipient of the first Bessemer Medal in 1874. That was fifty-two years ago, and it was now proposed to place upon the Roll of Honour the name of Sir Lowthian's most distinguished son—Sir Hugh Bell. Perhaps in the years to come the members might see the name repeated once more in order to maintain a continuity of the association of the name "Bell" with the great industry with which that name was so intimately bound up. On behalf of the Institute it gave him very great pleasure to present the Bessemer Medal to Sir Hugh Bell, and to express to Sir Hugh how much everyone connected with the industry owed to his family in general and to himself in particular. The Bell family had done much by word, by example, and by instruction to maintain and develop the great industry with which they had been so long associated.

Sir Hugh Bell, in reply, said that anyone who looked down the list of very distinguished names associated with the Medal

might well feel the same surprise that he himself did in finding that he was to be counted into that list. For upwards of twenty years he had taken some active part in selecting the persons on whom the honour should be bestowed, and never during that time, but once, and never during the preceding thirty years or so when the medal had been awarded by the Council to others (awards in which he had not had to take any part) had he found any reason to dissent from the choice of the Council—but once, as he had said, and that was the present occasion. When his colleagues, to his immense surprise, had been good enough to inform him that they intended to present the medal to him he had protested against their choice; he had felt that he was not worthy to appear among the distinguished list of persons headed by his father, in regard to whom Sir Peter had expressed that admiration which the members would not be surprised that he himself should feel as Sir Lowthian's son, and which he was glad to believe was shared in by all those who had come in contact with Sir Lowthian. That the members should have done him (Sir Hugh) the honour of adding his name to the list was, he would confess, not only a very great surprise but also a very great gratification. He would willingly have declined the honour, but the words which Sir Peter's predecessor in the Chair had used when he had made the announcement to him, and the way in which his colleagues on the Council had received that announcement, and the language which Sir Peter had used in presenting him with the medal, and the manner in which the statement had been received by the members of the Institute, made him feel that perhaps, like all other ironmasters, he was too modest. That, he thought, was an admitted peculiarity of everyone who happened to be engaged in the manufacture of "the metal of Mars." Therefore, in accepting the medal he did it, he hoped, with that suitable modesty which was becoming in any ironmaster, and which was particularly becoming, he ventured to think, on the present occasion, in the humble individual who had the honour of addressing the members; and he accepted the medal with the very deepest feelings of gratitude for the kindness which had instigated the members in adding him to the very distinguished list of previous recipients. Lord Melbourne had said that the great merit of the Garter was that there was no "damned

nonsense of merit about it." Personally, he could not say that of the Bessemer Medal, except perhaps in the present case. He had been given the medal for reasons which he could not fathom, but which, whatever they might be, left him under the feeling of the deepest gratitude for the kindly feeling of which the medal was the expression—an expression which he had had from his colleagues in the iron trade over the whole period of sixty-three years during which he had been engaged in the manufacture of iron.

The PRESIDENT then introduced to the meeting Mr. Kinander, Director of the Swedish Iron Institute (Jernkontoret), and Mr. Grabe, the Hon. Secretary of the forthcoming Stockholm Meeting. He was sure all the members were looking forward to taking part in the Autumn Meeting at Stockholm, and had the greatest pleasure in accepting the very kind invitation which had been extended to them by Mr. Kinander and his colleagues.

Mr. KINANDER then thanked the members very much for their kind reception of himself and Mr. Grabe, and said that the Swedish iron industry would be very glad to see the members of the Institute in Stockholm in the autumn.

The Presidential Address was then delivered (see p. 29), and the following papers were read and discussed :

Report on "Heterogeneity of Steel Ingots."

J. H. S. DICKENSON, "A Note on the Distribution of Silicates in Steel Ingots."

D. BROWNLIE, "Coal Blending."

W. ROSENHAIN, R. G. BATSON, and N. P. TUCKER, "Effect of Mass in the Heat Treatment of Nickel Steel." *

I. G. SLATER and T. H. TURNER, "The Hardness of Carbon Steels at High Temperatures."

A. R. PAGE, "The Hardening and Tempering of High-Speed Steel."

R. H. GREAVES and J. A. JONES, "The Ratio of the Tensile Strength of Steel to the Brinell Hardness Number."

* This paper was read and discussed, but pending the completion of further experiments by the authors, its publication has been deferred.

The following papers were taken as read :

A. E. Cameron and G. B. Waterhouse, "The Effects of Arsenic on Steel."

E. D. Campbell and H. W. Mohr, "Specific Resistance and Thermo-electromotive Potential of some Steels Differing in Carbon Content."

W. H. Dearden and C. Benedicks, "Magnetic Changes in Iron and Steel below 400° C."

W. W. Hollings, "Notes on the 'Combustibility' of Coke and Direct Reduction in the Blast-Furnace."

H. O'Neill, "Deformation Lines in Large and Small Crystals of Ferrite."

A. Osawa, "The Relation between the Space-Lattice Constant and the Density of Iron-Nickel Alloys."

T. E. Rooney and L. M. Clark, "The Estimation of Phosphorus in Steels containing Tungsten."

J. H. Whiteley, "Ghost Lines and Banded Structure of Rolled and Forged Mild Steels."

G. R. Woodvine and A. L. Roberts, "The Influence of Segregation on the Corrosion of Boiler Tubes and Superheaters."

Carnegie Research Grants.

The Secretary announced that applications for grants were received from fifteen candidates, and, after careful investigation of all the applications, the Council had decided that grants of the amounts shown below be awarded to the following applicants :

F. H. Arnfelt (Stockholm), £100, to carry out a research on the structure of iron-aluminium alloys, mainly by means of X-ray analysis.

V. N. Krivobok (Pittsburgh, U.S.A.), £100, to carry out a photo-microscopic study of recrystallisation of metals after cold-working.

A. G. Lobley and C. L. Betts (Manchester), £100, jointly to carry out an investigation on the viscosity of iron and steel at high temperatures.

A. R. Page (Birmingham), £100, to study the hardening and tempering of high-speed steels.

T. Ver (Budapest), £100, to study the effect of alternating stresses on the structure and mechanical properties of metals.

L. B. Pfeil (Swansea), £100, to continue his investigations on the growth and properties of single iron crystals. (Second grant.)

J. H. Partridge (Birmingham), £50, to continue his investigations on the electric and magnetic properties of cast-iron. (Second grant.)

Iron and Steel Institute.

PRESIDENTIAL ADDRESS.

By Sir WILLIAM PETER RYLANDS, J.P.

I believe it is many years since the Iron and Steel Institute elected a President not intimately associated with the actual manufacture of steel, and so unable to discourse learnedly upon the technology of the industry.

Those, however, who use steel, particularly if concerned with its manipulation in a cold state, represent an important and interesting branch of the industry, and if only as a healthy exception to an otherwise desirable rule, the occasional selection of a President from among their number may be both appropriate and wise.

In this country the manufacture of steel with the special object of submitting it to some process of cold-working has been practised but to a small extent, and I am satisfied that there has been a tendency in the past on the part of steel manufacturers to concern themselves chiefly with the production of a material which shall be in a suitable physical condition for finishing into plates, rails, and structural sections, rather than to treat it from a molecular point of view—a matter of high importance when the material is subjected to the searching effect of cold-drawing.

Speaking from the point of view of the wire industry, it was undoubtedly the experience of wire manufacturers prior to the war that, for the particular purpose of wire-drawing, certain steels which could be bought from the Continent presented qualities indubitably superior to the products of British steel-works. I attribute this partly, as I have already suggested, to the fact that steel-makers in this country were rarely concerned with producing a material specially suitable for cold-working, and partly to the unfortunate experience that wire billets of all carbons were offered from the Continent at prices which were unattractive to the British steel-maker, who found an adequate outlet for the product of his works in markets where there was an increasing demand for steel in a finished form.

A great change has taken place in the position of the British steel trade, and I may be permitted to express the opinion that this important requirement of steel for subsequent cold-working should receive more careful consideration by British steel-makers than I think has hitherto been the case.

It may be that, during my year of office, opportunities will present themselves for a more intimate discussion of this matter, but it will be readily appreciated that in the drawing of wire, where steel may be reduced, without any assistance from heat, to one-seventh of its original thickness, and elongated to thirty times its initial length, every particle of the steel must be subjected to a most searching test.

The problem presented to the steel-maker of manufacturing steel in batches of 40 tons and upwards, which when rolled into a billet shall exhibit the high degree of uniformity and mechanical perfection necessary for this purpose, is one which cannot be lightly approached.

It is manifest from what I have said that mechanical imperfections, almost microscopic in their character, attain serious proportions when the steel is elongated to the degree I have indicated, while chemical imperfections reflected in any lack of homogeneity are similarly revealed in the process of wire-drawing, and result in failure.

Success in the important industry of wire manufacture depends largely, if not entirely, upon the suitability of the material available. A very small percentage of defects greatly increases the cost of wire manufacture, while the many critically important purposes to which wire is applied in the fields of commerce demand a high degree of perfection if reputation is to be maintained and trade developed.

I mention this aspect of the steel industry for two reasons: the first, as some justification for your selection as President of one who represents this peculiar branch of the steel industry, without any reference to his personal qualifications for the office; and, secondly, as having some bearing upon the subject which I have chosen for my address.

It occurred to me that as there are now indications that the world has made some definite progress towards a return to normality, this occasion would not be inappropriate for laying

before the members of the Institute a picture of the past history of the steel industry as a matter of interest in itself, so that it may help us to form some reasoned judgment as to the prospects which the future holds in store.

For this purpose, with the assistance of Mr. Lloyd, to whom I am greatly indebted, I have prepared a chart (Plate I.), and in this connection I desire also to express my thanks to Sir William Larke for the valuable information he has placed at my disposal.

In this chart you will see that I have set out four main curves, one representing the total of the world's production of steel, and the other three the respective annual productions of the United States, the Continent of Europe, and of Great Britain.

I had expected to find a steady development in the world's consumption of steel, but I must admit to a feeling of some amazement when the curves were finally plotted out.

Measured in terms of present consumption, the total production of steel was almost insignificant up to forty years ago, and the year 1885 may be taken as marking the commencement of what may fairly be described as the "Steel Age," for which the discovery and development of the basic process was so largely responsible.

The most striking feature in the curve of the world's production of steel is the extraordinary uniformity in the rate of increase. Periodical fluctuations which must have taken place are entirely obscured in the curve plotted on bold lines, and up to 1914 instead of any inclination for the rate of increase to diminish, the curve tended continually to become more steep.

Looking at the curve it is difficult to avoid the conclusion that had the normal development of the world not been interrupted by the Great War, the world's consumption of steel would have continued to increase at a rate not dissimilar to that previously experienced, and might to-day have exceeded 100 million tons per annum.

In addition to certain subsidiary points of interest from which useful deductions may possibly be drawn, the curves bring to the eye three other main features. The first is the disturbing effect of the war, as illustrated by the curve movement between 1913 and the present time; secondly, the extraordinary similarity of

the total production of the United States and the Continent of Europe respectively during the pre-war period; and thirdly—a matter with which Great Britain is peculiarly concerned—the failure of Great Britain to maintain her position in relation to the United States and the Continent. Until the year 1890 the respective productions of Great Britain, the United States, and the Continent of Europe were approximately the same. Thereafter, the production of steel in the United States and on the Continent grew with amazing rapidity, while the production of Great Britain, although increasing, increased at a rate in no way comparable with the general increase in the world's demand.

In spite of the unsatisfactory condition of the steel industry during the past few years, the curve seems to suggest that the pre-war rate of expansion of the world's consumption has been approximately restored, and encourages the hope that in the next ten years an expansion even to the extent of thirty million tons a year is not beyond the bounds of possibility, or indeed of reasonable anticipation—an expansion which would go far to solve many of the troubles from which the industry is suffering. Unfortunately ten years is a long time, and British steel-makers, at all events, are much concerned to know what proportion of that estimated increase will fall to their lot, and how soon they can hope for a demand for British steel equal to British capacity to produce.

Many, if not all, the difficulties of our great basic industries are to be attributed to an arrest for practically ten years of the normal growth in the world's demand, an arrest which unfortunately was not accompanied by an arrest in the rate of increase in instruments of production. In the case of the steel trade, and other industries vitally concerned with the supply of munitions, there was in many countries a direct stimulus to an increase in plant, and an improvement can hardly be expected until that increased capacity is absorbed.

The curve of the United States production indicates that the capacity of that country both to produce and consume continued to grow during the period of the war at approximately the pre-war rate, and the market in the United States being such a large factor in the world's demand for steel, it is manifest that the total world's demand must be greatly increased before there is any

surplus demand available for the benefit of the European manufacturers.

Production on the Continent, after sinking to the depths of the post-war depression, has steadily risen, and in 1925 was but little short of the aggregate production of 1913. There is, however, a large amount of plant on the Continent still lying idle, of an estimated capacity of ten to fifteen million tons per annum, which can only be brought into operation by a corresponding increase in the world's demand.

The production of the United States in 1925 exceeded the highest level reached before the war by over ten million tons, and to absorb this increase and to occupy the idle European plant and provide for a normal increment in the steel requirements of the United States, there must be an increase in the world's demand of at least thirty million tons, or, say, ten years increment at the phenomenal rate of increase experienced prior to the war.

It is difficult to avoid the conclusion that even if the most optimistic anticipations are realised, the pressure of competition from the Continent during the next ten years must continue to be very severe. In this connection we must not fail to bear in mind that there are many new developments in steel manufacture in other countries of the world, and this increase in local production must diminish the share of the world's demand available to the old steel-producing nations.

Up to this point we have discussed the prospects of the steel industry, particularly from the point of view of the United States and the Continent of Europe, but we here are more intimately concerned with the well-being and future prosperity of the industry in Great Britain.

I have already drawn attention to the regrettable feature in the curves showing that from 1890 onwards Great Britain secured a negligible share in the phenomenal increase of the world's steel trade. Another regrettable feature is indicated in the closing years covered by the chart. While the world's demand, the production of the United States, and the production on the Continent showed during those two years a healthy and encouraging improvement, the production of Great Britain steadily fell, and if the suggestion is well founded that we cannot reasonably hope that the world's demand will, in less than ten years, overtake

the world's capacity to produce, the present trend of British production must give rise to feelings of profound anxiety.

It is no doubt true that, owing to the depreciation of the Continental exchanges, and the lag in internal values, as compared with world values, the Continental manufacturers have enjoyed an artificial advantage in competing with Great Britain, both in the British home market and in the markets of the world, and that we may hope that, in the course of a year or two, this lag will disappear and Great Britain will no longer suffer from that peculiar handicap.

Unfortunately, pre-war experience does not encourage us to anticipate that even under pre-war conditions—if these are to be regarded as the conditions of normality—British steel manufacturers will be able to compete with that success which present circumstances would seem to demand.

I do not think it can be denied that prior to the war the heavy competitive trade passed largely into the hands of the manufacturers on the Continent and in the United States, while such increase as was, in fact, secured by the British steel industry was rather in the direction of special lines and special qualities, and with the assistance of special conditions. Even for the home requirements of billets and sheet bars a large proportion was imported from abroad.

Clearly, with the great increase in British steel-making plant, it is now essential that the British steel manufacturers endeavour to secure a greater share of the heavy competitive trade, since it is doubtful whether any increase in the world's demand which can be anticipated during the next ten years will be accompanied by a sufficient increase in the special trades where Great Britain enjoys some peculiar advantage. Otherwise, without a serious reduction in productive capacity, the conditions of the British steel industry may be difficult for a considerable number of years to come.

These reflections invite consideration as to the reason why Great Britain failed to maintain her share in the general expansion of the world's trade, and after maintaining her position for twenty years up to 1890, thereafter was left behind in the race.

Great Britain was the cradle of the steel industry. Some of the most revolutionary advances in technique originated in Great Britain. She had bountiful supplies of cheap coal, and although

the Minette ore fields were of great assistance to the German industry, much of their steel was made from ore derived from other sources, presenting no particular advantage.

No doubt the United States derived great advantage from their immense and expanding home market; but as I have pointed out it is a notable feature that the increase in production on the Continent kept pace step by step with the corresponding increase in the United States, and it is not easy to appreciate the exact advantage enjoyed by the Continent of Europe over those who conduct the industry in this country.

Examining once more the history of the steel industry, it will be noted that its early development following on the introduction of the basic process was accompanied by a serious trade depression—a depression experienced not only in Great Britain, but also shared by the United States and the Continent.

You will observe that between the years 1885–1887 the price of Cleveland iron reached the lowest figure ever recorded.

Two important factors developed both in the United States and on the Continent approximately at that time: the first was the definite adoption by both the United States and Germany of a tariff policy designed to protect the home market; the second, arising without doubt out of the depressed condition of the industry, was the development of a high degree of internal organisation of the trade in both those countries.

At the depth of the depression the Carnegie Group was formed in the United States, followed later by the United States Steel Corporation, while in Germany syndicates were created for controlling the coal, pig iron, and finally steel, by means of the Stahlwerks Verband.

It would not be appropriate to lay any stress upon the desirability of an import duty, or to draw any deduction as to the advantage which accrued from that policy to the industry in the United States and in Germany. This is a matter of political controversy upon which different views are held, and the fact that that policy was followed in the countries adopting it by success, accompanied by relative failure in Great Britain, may have been merely a *post-hoc* and not a *propter-hoc* phenomenon.

We are on safer ground if we argue that organisation was the responsible and dominant factor.

There can be no doubt that the development of steel production

in America was closely associated with the internal organisation of the industry, and the corresponding improvement of organisation in Germany was similarly associated with corresponding successful development.

In few, if any, other industries are the costs of production so profoundly affected by large scale output and continuous operation as in the industries of steel and coal, and I am strongly convinced that the remarkable success of Germany and the United States in securing the lion's share of the increasing world's demand for steel is to be attributed to organisation directly aimed at securing that result.

As an illustration, on a visit I paid to Germany in the year 1912, I was informed that the cost of producing mild steel billets in Westphalia exceeded 80 Marks per ton, approximating very closely to the cost of manufacture in Great Britain. Those same billets were delivered to buyers in this country at a delivered price of under £4 per ton, and having regard to the cost of carriage it was manifestly impossible for the British manufacturers to compete.

No doubt the pursuit of special qualities is not entirely compatible with the policy of large and standardised production, and as long as the capacity of Great Britain can be satisfied by special business of this kind, and the manufacturers concerned are content, a valuable and important industry can be maintained ; but if, as appears now to be essential, Great Britain is to secure a greater share of the world's steel trade, it may be suggested that a different policy is imperatively demanded.

The commercial greatness of Great Britain was largely founded upon her production of coal and steel, and if that industrial position is to be maintained, I suggest that the problem should be approached from the broadest point of view in the interests of the country as a whole.

Some national responsibility attaches to the steel-makers of this country. It is not enough that a few steelworks should be conducted with success. It is rather a matter of great national concern that the industry should secure the greatest possible share of the world's steel trade, and give the utmost employment to the industrial workers of the country, and in this respect as I read the chart which I am venturing to submit to you, the prospect for the British steel industry during the next ten years affords ground for anxiety.

A further reflection, not altogether fanciful, is suggested by the amazing rate of increase in the world's consumption of steel. It is difficult to believe that a cheaper substitute for coal could ever be discovered for the manufacture of pig iron, and while we are assured that the coal resources of this country may be expected to last for some hundreds of years, that is a comparatively short period when measured in terms of geological time. Even, however, if we need not concern ourselves with anxieties which lie in the dim and distant future, the cost both of coal and of ore must increase under the law of diminishing returns. Within the recollection of many of us, slack was regularly sold by collieries at 3s. per ton at the pit, and forty years ago the price of Cleveland pig iron was so low as 32s. per ton; yet in spite of improvements in technique, the real costs of both coal and pig iron have greatly increased. It would appear certain that this tendency must continue, and the real cost of steel in this country, with the exhaustion of home supplies of ore and the inevitable increase in the cost of coal, will steadily rise. It is equally likely that certain other parts of the world more favourably situated in regard to ore and steel will enjoy an increasing economic advantage.

Practical steel-makers will no doubt be better able to judge how far the cost of home supplies of ore will be affected during the next ten or twenty years, but taking a broad view, this reflection, so far as it is of subtance, emphasises the importance of scientific organisation of the industry, both on the technical and commercial side.

The Iron and Steel Institute has done much in the past to assist in technical development, but it seems to me that still more intimate co-operation is now necessary, and that the vast world's consumption of iron and steel demands correspondingly large scale productions, the co-ordination of technical knowledge, and the most efficient application of every technical advance if a steel-producing nation is to hold its position in the race.

The manufacturers in the United States of America, and on the Continent, seem to have realised this, and have set an example which might wisely be followed in this country if the steel trade of Great Britain is to overcome the pressing difficulties of the next ten years, to which I have invited your attention, and of the more remote period when we may gradually lose some of the national advantages which we at present enjoy.

Votes of Thanks.

Sir Robert Hadfield, in proposing that the best thanks of the members be given to the President for his admirable Presidential Address, said he was glad to note that the President had confirmed an estimate which he had made in his own Presidential Address of many years ago—that the steel production of the world would very shortly reach 100,000,000 tons. In considering that large tonnage it should be borne in mind that it really indicated a very much larger quantity—that was to say, a ton of steel now possessed much more efficiency. A very large amount of the production to-day was of special steels, which took the place of a much larger weight of the ordinary steel. One admirable thing about the Presidential Address was that the President had not lost his head in any way. Everyone knew that the industry was suffering from a great depression, but instead of giving an address of a depressing character the President had delivered a highly sensible and optimistic address. He had stated that the industry could look forward, by developing its methods and increasing its knowledge of the manufacture of iron and steel, to a very bright future; and personally he could not help thinking that that would be so. When the end of the present terrible troubles came there was no doubt that this country would have a great future in the production of iron and steel.

The vote of thanks was then put and carried with acclamation.

On the motion of the Chairman, at the conclusion of the meeting a hearty vote of thanks was passed to the Institution of Civil Engineers for extending to the Institute the hospitality of the use of their rooms for the purpose of holding the meeting.

Iron and Steel Institute.

REPORT ON THE HETEROGENEITY OF STEEL INGOTS.

By a SUB-COMMITTEE, on Behalf of the No. 5 Committee (Metallography, Physics, and Chemistry) of the Iron and Steel Institute.

At a Meeting of the No. 5 Committee (Metallography, Physics, and Chemistry) of the Iron and Steel Institute held on May 7, 1924, it was unanimously agreed to request Dr. Hatfield to form a Sub-Committee for the purpose of studying the problems of inclusions in steel and of the heterogeneity of steel ingots.

The Sub-Committee was ultimately constituted as follows:

Mr. T. P. Colclough (The Park Gate Iron and Steel Co., Ltd.).
Mr. W. J. Dawson (Messrs. Hadfields, Ltd.).
Mr. J. H. S. Dickenson (Messrs. Vickers, Ltd.)—*Vice-Chairman.*
Mr. A. P. Hague (Messrs. Cammell Laird & Co., Ltd.).
Dr. W. H. Hatfield (The Brown-Firth Research Laboratories)—*Chairman.*
Mr. E. F. Law (Messrs. Sir W. G. Armstrong, Whitworth & Co., Ltd.).
Mr. S. A. Main (Messrs. Hadfields, Ltd.).
Mr. T. M. Service (Messrs. Wm. Beardmore & Co., Ltd.).
Mr. J. H. Whiteley (The South Durham Steel and Iron Co., Ltd.).

The Sub-Committee is now able to present this, its first Report. The work is confined to a consideration of the degree and nature of the heterogeneity found in carbon steel ingots. This has been made possible through the generosity of the firms, with whom the members are associated, in supplying data and in facilitating and financing a most costly form of investigation.

The Report is divided into the following sections:

Section I.—Introduction.
Section II.—The methods employed in studying the sectioned ingots.
Section III.—Data obtained from representative steel ingots.
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HETEROGENEITY OF CARBON STEEL INGOTS.

SECTION I.—*Introduction.*

A knowledge of the degree of heterogeneity which is to be found in steel ingots of all kinds and of the manner in which it arises is of much interest both from the technical as well as from the scientific point of view. For certain types of engineering projects developed during the last few years increasingly heavy ingots have been required and made, and the variations in the mechanical properties and chemical composition have sometimes proved disconcertingly wide. It has long been generally understood that as the mass of the ingot is increased the heterogeneity becomes more accentuated, and one of the objects of the Sub-Committee has been to give a more quantitative expression to the degree of heterogeneity which may be reasonably expected. The evidence shows the variation in composition to be of such an order that the facts should be made known, as they are of the utmost importance both to steel-makers and the users of ingots.

The evidence presented is derived from the examination of a large number of ingots ranging from 15 cwts. to 172 tons in weight. Brief particulars of the actual ingots selected as examples for consideration are given in Table I. (p. 49). All of them may be regarded as reasonably representative of the type of ingot and the class of steel to which they belong when manufactured under good conditions.

It is sometimes considered that the heating of steel ingots and maintaining them at high temperatures for long periods of time, preparatory to forging and rolling, will, to a large extent, remove the heterogeneity, the idea being that prolonged heating brings about homogeneity by the diffusion of the elements segregated

in the cast state. Such an opinion, however, requires considerable modification, in view of the fact that some of the larger examples studied display pronounced heterogeneity, notwithstanding that they have been reheated and bloomed prior to sampling for analysis, thus clearly indicating the degree to which heterogeneity exists after such prolonged heating of the ingot.

It may first of all be stated that no ingot ever produced is completely homogeneous, however carefully the steel may have been made and cast. Further, the intensity of the segregation increases with the size of ingot, as is shown by the increasingly wide variation in the carbon, sulphur, and phosphorus throughout the mass.

Although ordinary commercial ingots cast in chill moulds, if sectioned longitudinally along the axes and examined by various methods, disclose considerable structural variation, owing to differences in size, shape, manner of casting and composition, yet they all possess certain common characteristics which are readily observable. Their similarity in regard to these technically important structural features is due mainly to the fact that the molten steel when poured into the mould requires a period of time for complete solidification. Freezing commences at the outer surface and proceeds by selective crystallisation, with the result that the unavoidable phenomena of shrinkage and segregation must always proceed on similar lines, and lead in varying degree to similar effects in all cases.

Turning now to the structure of ingots as disclosed by the examination of a longitudinal section taken along the axis: All steel ingots without exception show a region of columnar crystals which have grown from the outer surface to varying distances inwards towards the central axis; zones of segregation which occur in distinct and characteristic forms; a principal axial shrinkage cavity usually confined to the upper end of the ingot and called "pipe"; and minor, often very small, shrinkage cavities along the central axis below the upper one, usually accompanied by segregate. Generally, also, there is a more or less conical region in the bottom portion of the ingot, in the neighbourhood of which the carbon, sulphur, and phosphorus are lower than in other regions, though the amount of non-

metallic inclusions may be greater; and an annular zone of free crystals broadening towards the base, lying between the external columnar region, the more or less unsound central axis and the conical region to which reference has just been made. Through this annular zone extend (more particularly in large ingots) irregular, vertically arranged threads of segregate, which become more emphasised as the size of the ingot increases. It is these threads which appear as "ghost lines" in forgings and rolled products.

It is the development of these well-defined characteristics which constitutes the usual heterogeneity of any steel ingot, and an attempt has been made by the Sub-Committee to show how they appear in carbon steel ingots of the varying sizes as stated.

In considering the freezing of large masses of steel, non-metallic impurities, apart from sulphides, are invariably present in greater or less amount in the molten steel, due to traces of reaction products remaining, which are not eliminated owing to their size and the viscosity of the metal. Under the most skilful practice in refining it is not possible to eliminate entirely the oxygen always present in certain forms, and to bring the steel to the perfect state in which non-metallic inclusions of oxide origin are not present. It should also be borne in mind that liquid steel is susceptible to oxidation by the atmosphere through which it has to pass during the process of teeming, and there is a definite tendency to the formation on the molten surface of the metal of a certain amount of oxide which the most careful technique cannot always entirely prevent becoming entangled in the freezing mass. This aspect of inclusions must, however, be left to be dealt with later by the Sub-Committee after consideration of ingot structure, which is of primary importance as indicating the sequence of the freezing process.

The internal character of an ingot is naturally profoundly affected when the liberation of gas during solidification is sufficiently rapid to result in the formation of blowholes, but such incompletely "killed" steel will not be dealt with in this Report.

The metallographic study of a longitudinal section of any ingot made from steel which has been refined or treated so as

to solidify without the formation of blowholes reveals the following phenomena:

1. A very thin extreme outer skin of ill-defined crystalline structure is generally observed—*i.e.* true chill crystals.
2. From the inner surface of this very thin layer a growth of columnar crystals appears, extending inwards (Zone 1); the thickness of this layer will depend upon the temperature of the liquid steel, rate of teeming, the temperature, thickness, and nature of the mould, the size of the ingot, and composition of the steel.
3. Proceeding towards the centre of the ingot, it will be found that beyond the zone of columnar crystals lies a region richer in segregates, the segregate usually occurring in the form of spheroids or thin strings. This zone of segregation (Zone 2) is of annular form, its inner boundary having roughly the form of a truncated cone or pyramid, according to the shape of the ingot.
4. Sulphur prints and etchings show that inwards from Zone 2 there is a central zone (Zone 3), in which the crystals may cease to possess the hitherto well-marked columnar form. In the lower half of this zone the steel is lower in carbon, sulphur, and phosphorus than the original liquid steel—the lower central axis is indeed the purest part of the ingot. In the upper half of the ingot this central zone approaches the average composition of the steel, but in many cases local segregation appears within it, assuming frequently a roughly V-shaped form.
5. At the extreme upper end of Zone 3 there is a region of segregation.
6. The axial portion of the ingot is always rather unsound, and, except in the lower part, seldom quite free from segregation.
7. Unsoundness is sometimes found, though to a less degree, in vertical planes radiating to the corners of the ingot and in inclined planes from the edges of the base of the ingot.

Besides presenting studies of longitudinal sections along the axis, the data have been amplified by the addition of a sulphur

print (Fig. 4, Plate VII.) showing a section cut transversely midway in the length of a bloom 40 inches in diameter, produced from an ingot weighing 32 tons 17 cwts. 2 qrs., and measuring 49 inches at the top and 45 inches at the bottom across the flats. The heterogeneity disclosed in this cross-section should be compared with that shown in the longitudinal sections.

With two exceptions the ingots dealt with have been cast in chill cast-iron moulds. One small ingot was cast in a sand mould, the other in a mould lined with a refractory " composition." The comparison of these two ingots with those cast in chill iron moulds is of interest for two reasons. In the first place the effect of the absence of the normal chill is observable, and in the second a clear indication is given of the degree of heterogeneity which is likely to occur in ordinary steel castings.

In considering the various data presented, it should be remembered that the ingots have been produced by different methods of manufacture—namely, the acid open-hearth, the basic open-hearth, the converter, and the electric process. They have all been cast under conditions normal to the practice in the works in which they have been produced. But clearly these conditions are to some extent variable. Under the heading of " variables " may also be included the reactions in the furnace, composition, casting temperature, speed of teeming, design of ingot mould, and last, but not least, the size of the ingot. As all these individual factors may influence the mechanism of the freezing, they should be borne in mind when considering the data presented with each of the examples.

It is not within the scope of the present Report to indicate or to suggest modifications in the process of manufacture with a view to modifying the degree of heterogeneity, but only to present to the Members an accurate indication of the degree which may reasonably be expected in ingots representative of the present state of the art of steel manufacture. Although steel-makers have for many years devoted much time, study, and expenditure to the problem, it is felt that much more remains to be done in investigating the causes of heterogeneity, particularly as regards fundamental data, and it has been the endeavour of the Committee to increase the knowledge at present available on the subject.

SECTION II.—*The Methods Employed in Studying the Sectioned Ingots.*

For the adequate study of the heterogeneity existing in an ingot, it is necessary that a complete section shall be prepared. Generally, and unless stated to the contrary, each ingot dealt with in this Report was sectioned along its axis, thus exposing for examination a surface representative of the whole of the ingot. In this method of preparation the machined surface is either ground or ground and polished, and is then ready for the further work that has to be done upon it. In this condition the surface is a uniform bright metallic one, and, apart from the pipe cavity at the top of the ingot, discloses no other indication of note except, perhaps here and there, slight minor cavities and looseness along the central axis.

When, however, this prepared surface is etched by some suitable etching medium, both the crystalline character of the steel and a very definite heterogeneity are in all cases disclosed. The chemical action upon the surface of the section is by no means uniform, and whilst certain areas are not much affected, others are readily attacked. It will thus be seen that by etching heterogeneity not previously observed is definitely brought out. The etched surfaces of the ingot sections are then photographed for record purposes. This method of investigation is well illustrated by Fig. 1 (Plate II.), which reproduces the evidence obtained in this manner concerning the heterogeneity in a 10-ton ingot.

It may perhaps be of interest to say a few words concerning the several methods of etching such surfaces. One of the most commonly used reagents is that known as Heyn's reagent. This reagent consists of an 8 to 10 per cent. solution of copper ammonium chloride in water, and is particularly useful for disclosing segregation on a well-polished surface. However, in the use of Heyn's reagent copper is deposited on the steel, and if the reagent is left in contact too long difficulty may be encountered in removing it.

Humfrey's modification of Heyn's reagent consists of etching, first of all, with an 8 to 12 per cent. solution of copper ammonium chloride in water for from ten minutes to half an hour, and then etching for a further half-hour with a similar solution,

containing in addition $2\frac{1}{2}$ to 5 per cent. of hydrochloric acid. The steel is then given a third half-hour with an addition of 15 per cent. of hydrochloric acid to the solution (with possibly an intermediate period with $7\frac{1}{2}$ to 10 per cent.), and if necessary still stronger acid solutions are employed to obtain the required effect. One interesting advantage of this process is that the structure stands out in relief and may be reproduced by contact printing.

For general works purposes, however, nitric acid solutions in either water or alcohol are sufficiently effective to give satisfactory evidence of the degree of heterogeneity. For revealing segregation in large masses of steel, where the preparation of the surface might possibly not be of a very high order, nitric acid is to be recommended. It is advisable to commence etching with 2 per cent. acid, following by increasing the strength to between 5 and 8 per cent. and then finishing with 10 per cent. By this means a fairly deep etch, capable of obliterating scratches, is obtained in a reasonable time.

The Baumann sulphur printing method is largely used, and the procedure consists of pressing a photographic bromide paper soaked in dilute sulphuric acid on to the surface under examination. The sulphuric acid in the bromide paper reacts with the sulphide in the steel, liberating sulphuretted hydrogen, which in turn reacts with the silver bromide in the vicinity, producing dark-coloured sulphide of silver. The sulphur print, therefore, gives a graphic but intensified representation of the degree of heterogeneity, based upon an unequal distribution of the sulphur. As will be seen from a study of the examples here presented, the heterogeneity consists essentially in the segregation together of the carbon, sulphur, and phosphorus, while the manganese and silicon segregate in a much less degree. The segregation of the sulphur, as shown by the sulphur print, may be taken as indicative of the general heterogeneity of the material. Whilst one or two of the examples given in this section are illustrated by photographs of the etched specimen, most of the examples are illustrated by means of sulphur prints.

The description and discussion of other etching media which have been suggested and used with more or less success for this type of investigation are necessarily omitted.

Besides the visual methods of investigation above described, a large number of samples representative of the composition of the ingots at many points have been taken, and the carbon, manganese, silicon, sulphur, and phosphorus have been carefully determined. But such analyses, after all, are only average indications of the composition of the portion of steel included in the drillings. A $\frac{1}{2}$-inch or $\frac{3}{8}$-inch diameter hole is, as will be seen later, big enough to include local segregation streaks together with normal steel. Another aspect of the results of analyses should be borne in mind. In the case of each example, except No. 9, the analyses were carefully conducted in the laboratory of the works where the ingot was made, and therefore all the figures for any one ingot are strictly comparable.

On a number of the ingots hardness determinations were made over the whole section, either by the Brinell or the Shore method.

SECTION III.—*Data Obtained from Representative Steel Ingots.*

In this section the data derived from the examination of the various representative ingots are presented for each example as far as obtained. A summarised statement of all the examples put forward will be found in Table I., and the main features of each are given in detail below.

Example 1.—An ingot cast in a sand mould. Weight, 14 cwts. 3 qrs. Size, $11\frac{7}{8}$ inches square at the top, $10\frac{3}{16}$ inches square at the bottom; 3 feet 9 inches in length, excluding head. Top poured.

The ingot was cast from converter steel of the following composition: Carbon 0·48, manganese 0·83, silicon 0·27, sulphur 0·041, phosphorus 0·028 per cent.

For this ingot no other data is available beyond that shown in the sulphur print, reproduced as Example 1 (Plate V.), which will be seen to bring out very marked segregation effects in the outer zones of the ingot and also down the central axis.

Example 2.—An ingot cast in a chill mould. Weight, 1 ton 5 cwts. Size, 13·825 inches in diameter at the top of the chill, 13 inches in diameter at the bottom of fluting; 5 feet 5 inches in length in chill. Top poured.

FIG. 1.—A typical presentation of the disclosure of heterogeneity obtained by etching a polished section of a steel ingot.

[To face p. 48

FIG. 2.—An etched section through the wall of an ingot disclosing the upward trend of the columnar crystals.

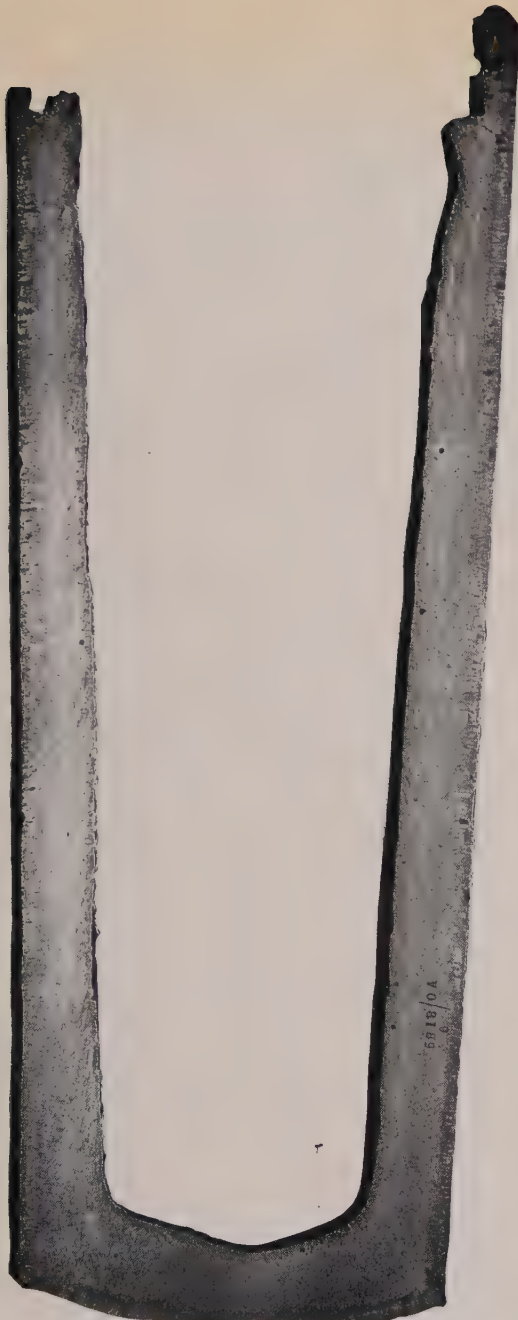
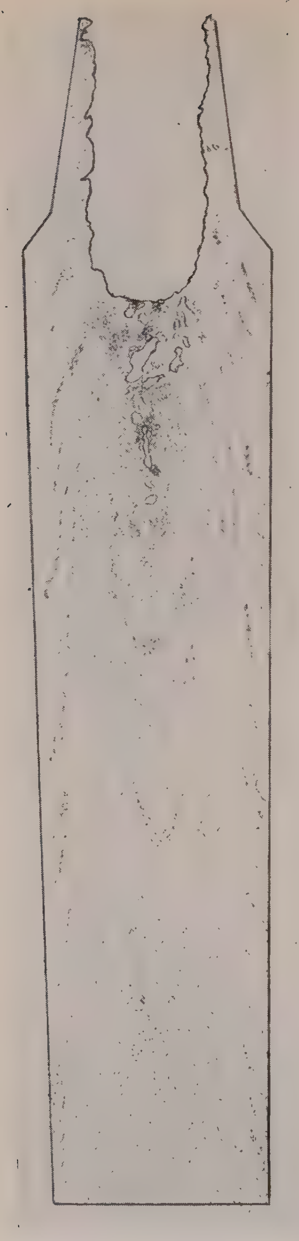
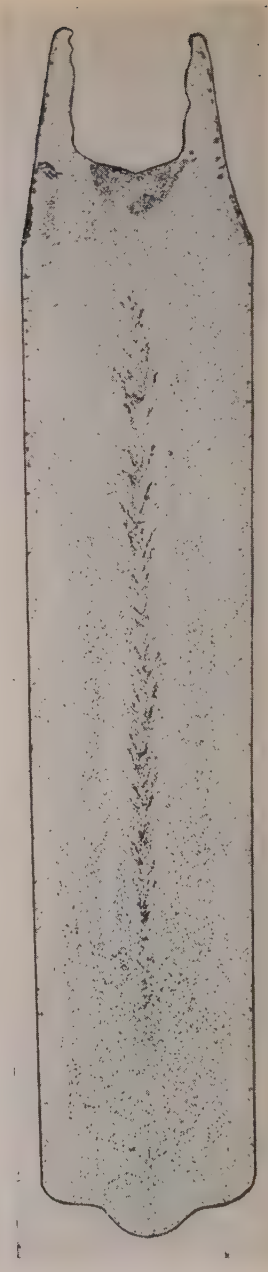


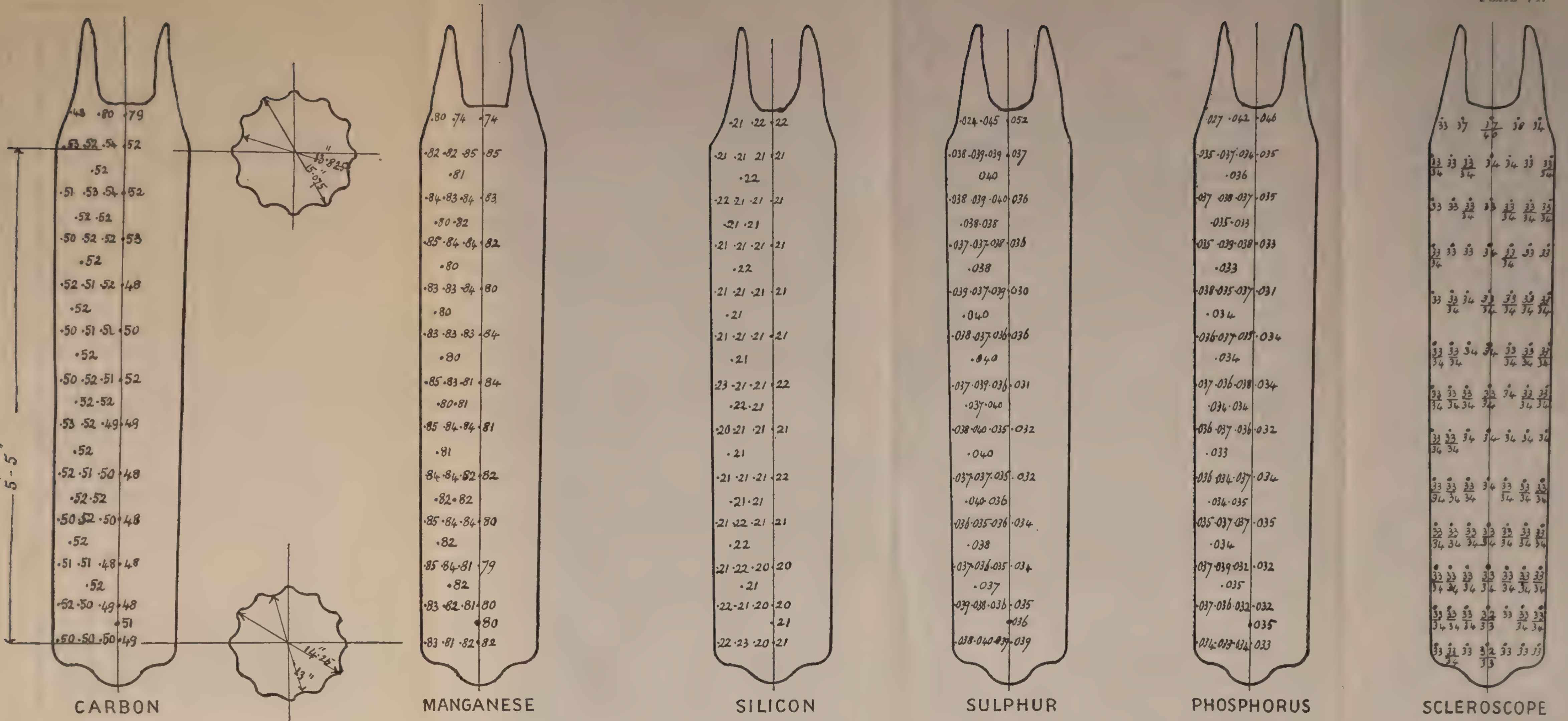
FIG. 3.—A section through an ingot after the thickness of wall shown had solidified and the remaining liquid steel had been poured out.



Example 1.—15 cwt. Ingot.
Sulphur print.



Example 2 g.—$1\frac{1}{4}$-ton Ingot.
Sulphur print.



Cast Analysis, 0·50. *a.* — Cast Analysis, 0·83. *b.* — Cast Analysis, 0·21. *c.* — Cast Analysis, 0·037. *d.* — Cast Analysis, 0·036. *e.* — *f.*

Example 2.—1½-ton Ingot. Distribution of Elements and Hardness.

Example.	Description. All Ingots were Top Poured.	Weight. Tons.	Weight. Cwts.	Size.	Kind of Steel.	Returned Typical Analysis. C. Per Cent.	Mn. Per Cent.	Si. Per Cent.	S. Per Cent.	P. Per Cent.
1	Sand ingot, square		$14\frac{3}{4}$	Top, $11\frac{3}{8}$ in. square; bottom, $10\frac{3}{16}$ in. square. 3 ft. 9 in. in length	Acid converter	0·48	0·82	0·27	0·041	0·028
2	Ordinary chill ingot, twelve-sided	1	5	Top, 1 ft. $1\frac{7}{8}$ in. across; bottom, 1 ft. 1 in. across. 5 ft. 5 in. in chill	Acid Siemens	0·50	0·83	0·21	0·037	0·036
3	Ordinary chill ingot, square	2	10	Top, 1 ft. 7 in. square; bottom, 1 ft. 5 in. square. 4 ft. 8 in. in chill	,,	0·41	1·06	0·48	0·056	0·052
4	Ordinary chill ingot, rectangular	2	15	Top, 1 ft. $6\frac{1}{2}$ in. × 1 ft. $11\frac{1}{2}$ in.; bottom, 1 ft. 5 in. × 1 ft. 10 in. 3 ft. 8 in. in chill	,,	0·34	0·72	0·282	0·04	0·043
5	Ordinary chill ingot, rectangular	2	$18\frac{1}{2}$	Top, 1 ft. $11\frac{3}{4}$ in. × 1 ft. $5\frac{5}{8}$ in.; bottom, 1 ft. $9\frac{1}{2}$ in. × 1 ft. $3\frac{1}{2}$ in. 5 ft. 2 in. in chill	,,	0·34	0·70	0·163	0·049	0·039
6	Ordinary chill ingot, twelve-sided	2	18	Top, 1 ft. $8\frac{1}{2}$ in. across; bottom, 1 ft. $7\frac{1}{2}$ in. across. 5 ft. 7 in. in chill	,,	0·60	0·77	0·229	0·038	0·040
7	Ordinary chill ingot, square	3	5	Top, 1 ft. 8 in. square; bottom, 1 ft. 6 in. square. 5 ft. 6 in. in chill	Basic Siemens	0·40	0·83	0·12	0·034	0·042
8	Ordinary split-chill ingot, square	8	0	Top and bottom, 3 ft. 4 in. × 2 ft. 1 in.	,,	0·39	0·96	0·08	0·025	0·024
9	Loam ingot, round	8	5	Diameter, 1 ft. 10 in.; 15 ft. $7\frac{1}{2}$ in. long	,,	0·21	0·51	0·04	0·027	0·059
10	Ordinary chill ingot, octagon	10	10	Top, 3 ft. across; 5 ft. long	Electric	0·30	0·74	0·13	0·017	0·010
11	Ordinary chill ingot, octagon	20	0	Top, 3 ft. 1 in. across; bottom, 2 ft. 11 in. across. 10 ft. in chill	Acid	0·21	0·66	0·169	0·032	0·040
12	Ordinary chill ingot, octagon	24	$17\frac{1}{4}$	Top, 3 ft. 7 in. across; bottom, 3 ft. 4 in. across	,,	0·44	0·78	0·29	0·033	0·042
13	Two chill ingots (*a*) and (*b*), octagons	54 each			,,	...	...	...	...	...
14	Bloom of chill ingot, octagon	64	0	Top, 4 ft. $11\frac{1}{2}$ in. across; bottom, 4 ft. $7\frac{1}{2}$ in. across. 13 ft. 5 in. in chill	,,	0·40	0·63	0·16	0·035	0·038
15	Chill ingot, octagon	110	0	Top, 6 ft. $10\frac{3}{4}$ in. across; bottom, 5 ft. 11 in. across. 11 ft. 11 in. in chill	,,	0·27	0·715	0·244	0·033	0·024
16	Chill ingot (octagon) and bloom	172	0	Top, 6 ft. 4 in. across; bottom, 6 ft. across. 17 ft. in chill	,,	0·32	0·79	0·13	0·027	0·033

The surface of the mould consisted of twelve concave sides. The steel was manufactured by the acid Siemens process and had the following composition: Carbon 0·50, manganese 0·83, silicon 0·21, sulphur 0·037, phosphorus 0·036 per cent.

The charts for Example 2, marked *a*, *b*, *c*, *d*, and *e* respectively (Plate VI.), show detailed analyses indicating the distribution of the elements carbon, manganese, silicon, sulphur, and phosphorus over the complete section from the central axis to the outside of the ingot. Example 2 *f* presents a record of the hardness values obtained by scleroscope tests over the whole of the section of this ingot. Example 2 *g* (Plate V.) is a reproduction of the sulphur print. In the case of this ingot it will be seen that there is very little segregate apart from that along the central axis and in the feeder head.

Example 3.—An ingot cast in a chill mould. Weight, 2 tons 10 cwts. Size, 19 inches square at the top of the chill, 17 inches square at the bottom; 4 feet 8 inches in chill. Top poured.

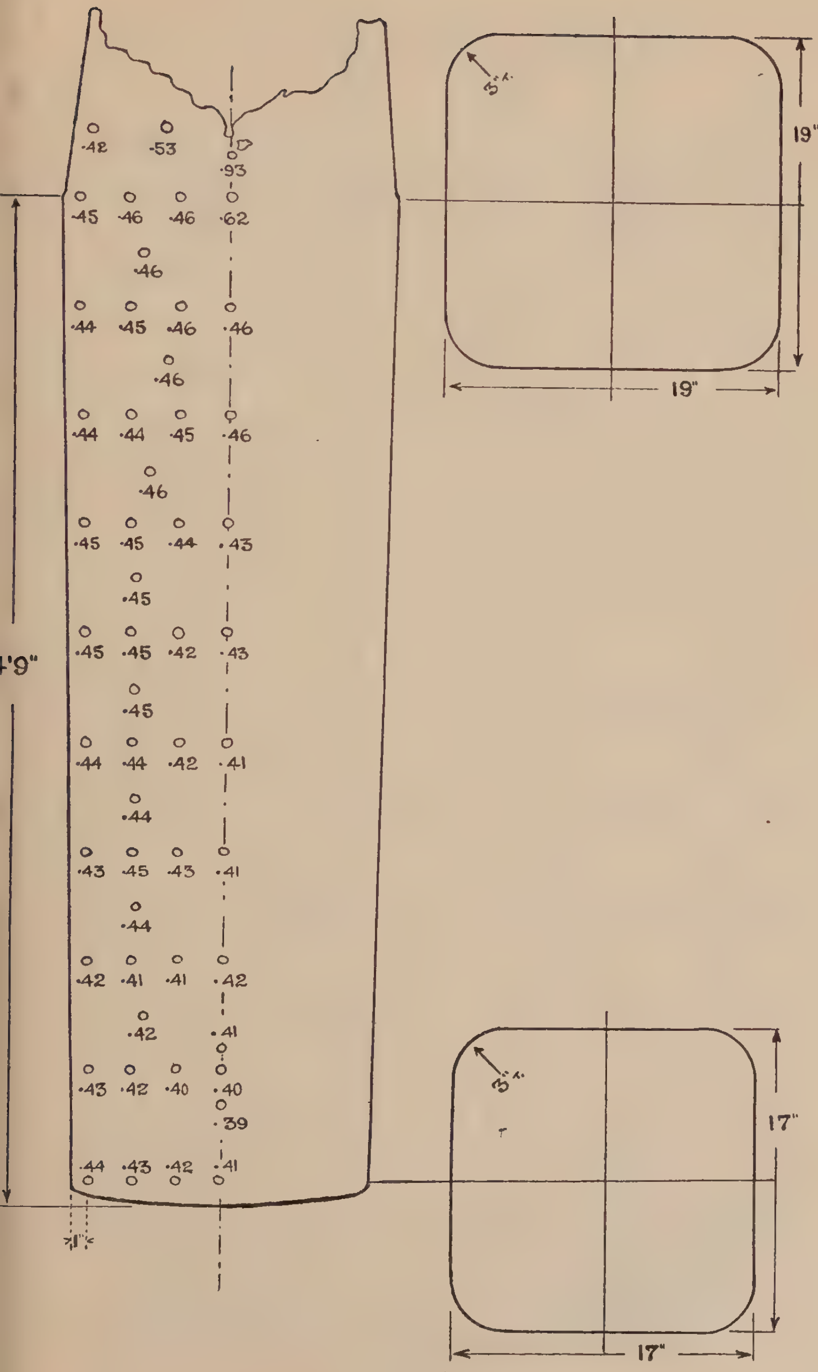
The steel was manufactured by the acid open-hearth process, and was of the following composition: Carbon 0·41, manganese 1·06, silicon 0·48, sulphur 0·056, phosphorus 0·052 per cent.

The charts for Example 3, marked *a*, *b*, *c*, *d*, and *e* respectively (pp. 51–53), show the results of analyses indicating the distribution of the several elements carbon, manganese, silicon, sulphur, and phosphorus over the entire longitudinal half-section of the ingot from the central axis to the outside. In Example 3 *f* (p. 54) the results of scleroscope hardness determinations are given, and Example 3 *g* is a reproduction of the sulphur print obtained from the section of this ingot, showing the development of well-marked segregate lines in a zone intermediate between the outer surface of the ingot and the central axis. There are also definite segregation effects along this axis.

Example 4.—An ingot cast in a chill mould. Weight, 2 tons 15 cwts. Size, 18½ in. × 23½ in. at the top of the chill, 17 in. × 22 in. at the bottom; 44 inches long in chill. Top poured.

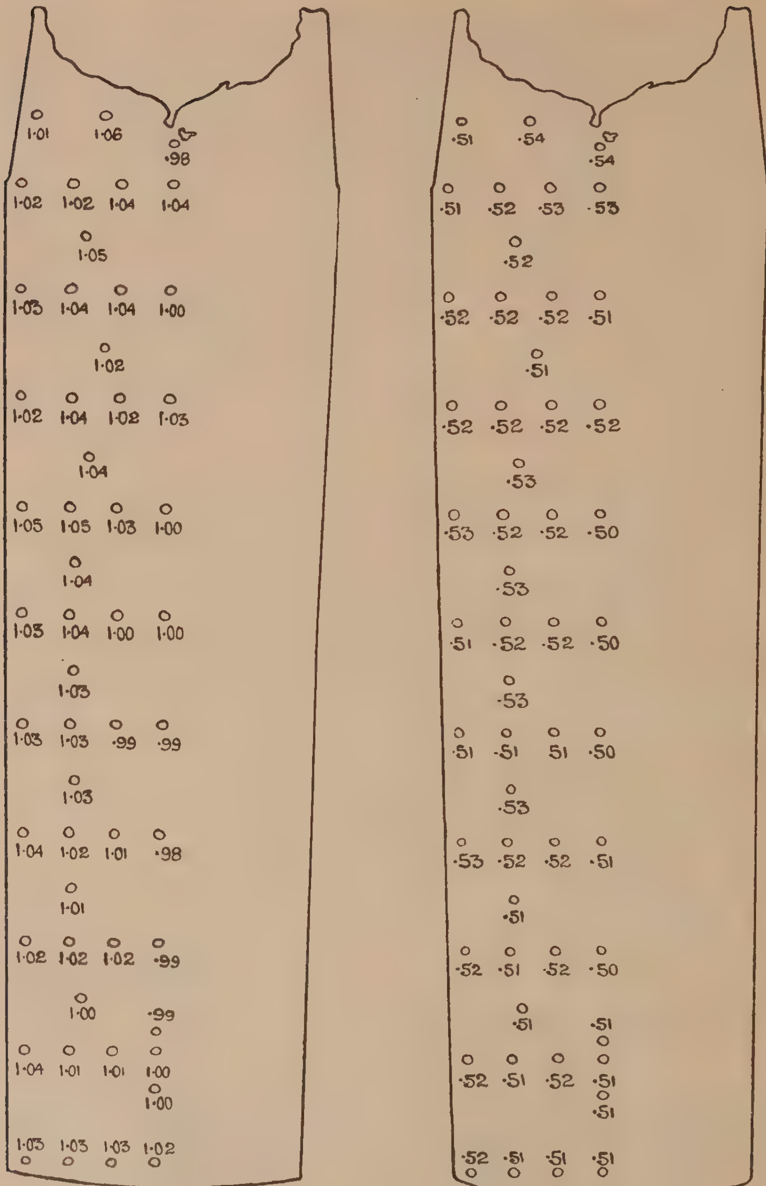
The steel was manufactured by the acid open-hearth process, and was of the following composition: Carbon 0·34, manganese 0·72, silicon 0·282, sulphur 0·04, phosphorus 0·043 per cent.

The charts for Example 4, marked *a*, *b*, *c*, *d*, and *e* respectively (Plate IX.), show the results of the analyses for carbon, manganese,



Cast Analysis, 0·41.

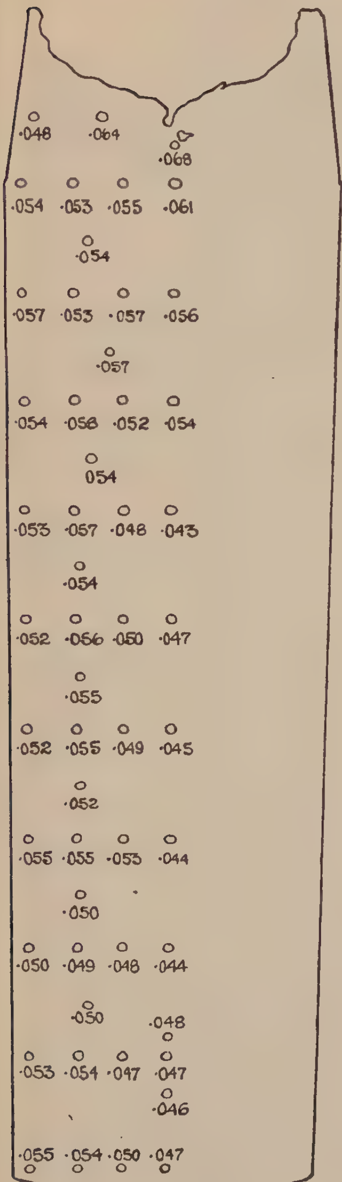
EXAMPLE 3.— ½-ton Ingot. *a.* Distribution of Carbon.



b. MANGANESE
Cast Analysis, 1·06.

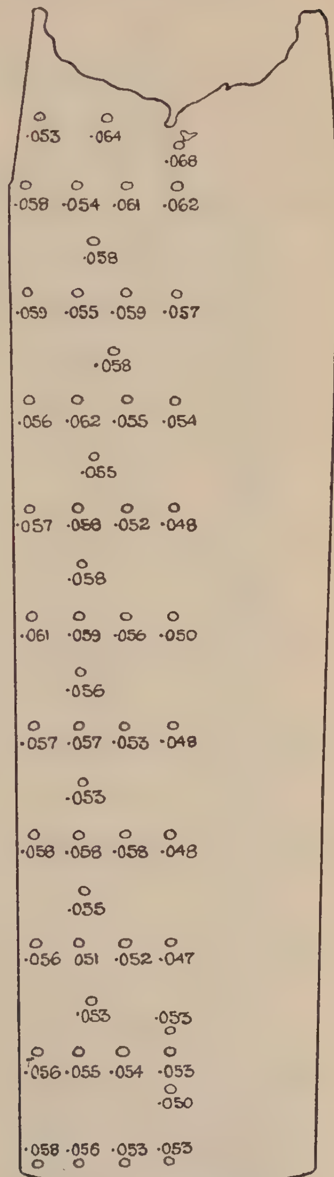
c. SILICON
Cast Analysis, 0·48.

EXAMPLE 3.—2½-ton Ingot. Distribution of Elements.



d. SULPHUR

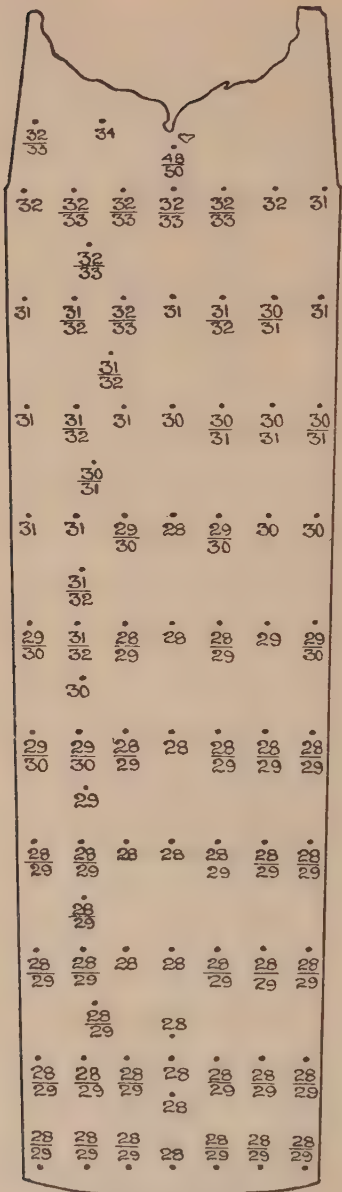
Cast Analysis, 0·056



e. PHOSPHORUS

Cast Analysis, 0·052.

EXAMPLE 3.—2½-ton Ingot. Distribution of Elements.

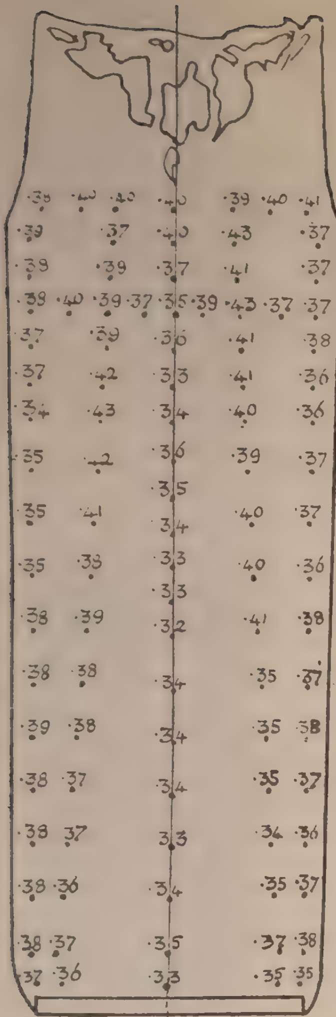


f. SCLEROSCOPE HARDNESS

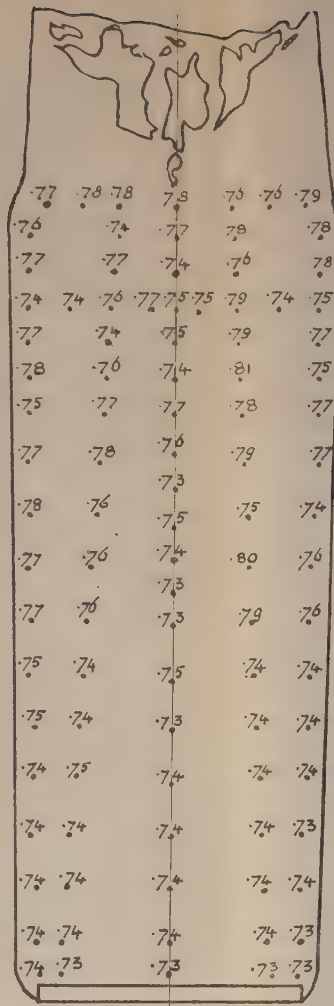
g. SULPHUR PRINT

EXAMPLE 3.—2½-ton Ingot.

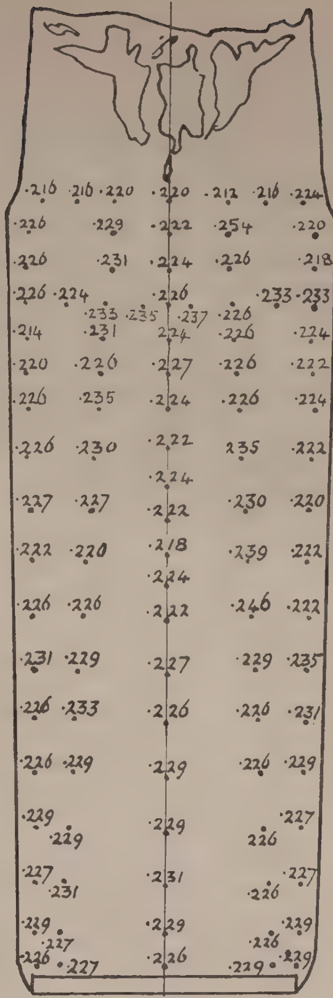
FIG. 4.—Sulphur print of the cross-section midway in the length of a bloom, 40 inch diameter, from an ingot weighing 32 tons 17 cwts. 2 qrs.



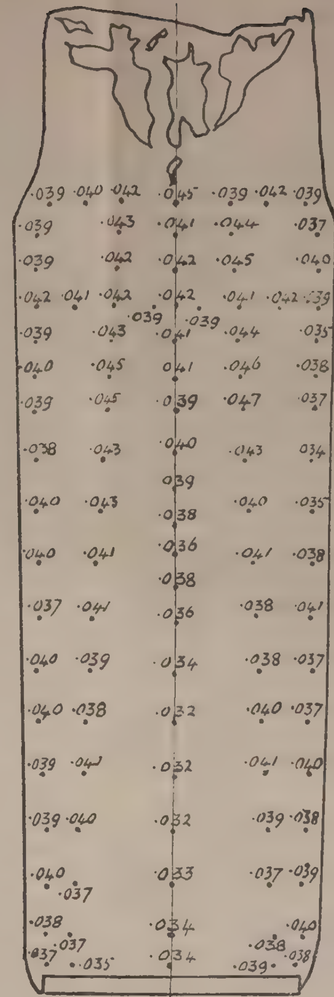
CARBON
Cast Analysis, 0·34.
a.



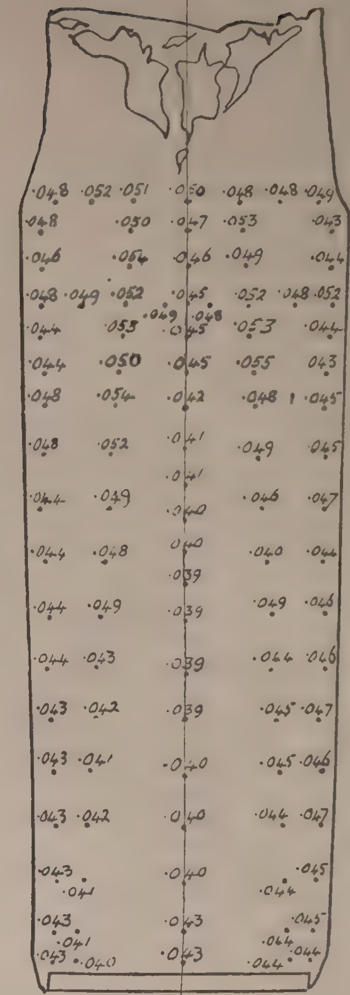
MANGANESE
Cast Analysis, 0·72.
b.



SILICON
Cast Analysis, 0·282.
c.

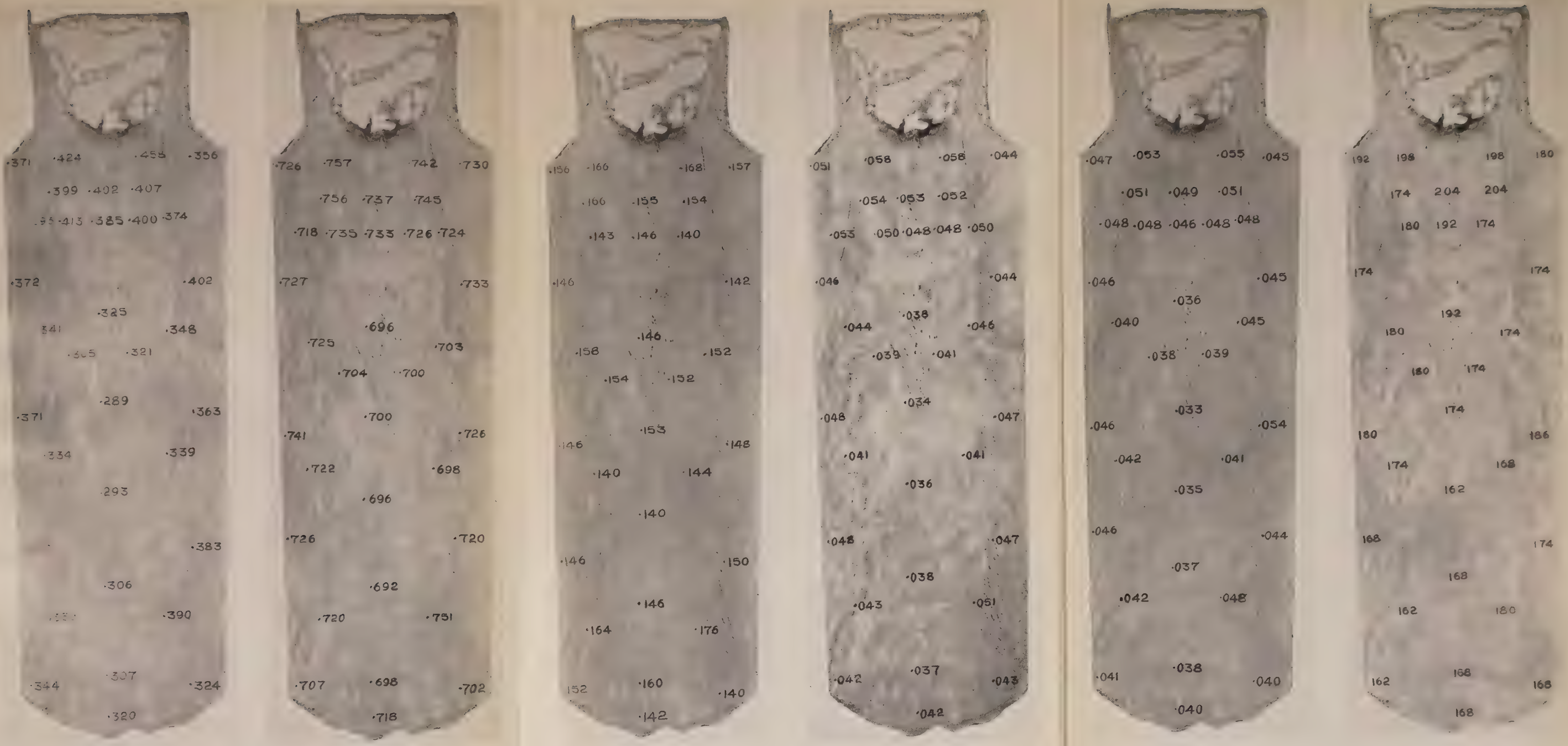


SULPHUR
Cast Analysis, 0·04.
d.



PHOSPHORUS
Cast Analysis, 0·043.
e.

Example 4.—2¾-ton Ingot. Distribution of Elements.



Cast Analyses 0·34
(a) Carbon.

0·70
(b) Manganese.

0·163
(c) Silicon.

0·049
(d) Sulphur.

0·039
(e) Phosphorus.

(f) Brinell hardness.

Example 5.—3-ton Ingot. Distribution of elements, and hardness.

Cast Analyses 0.60
(a) Carbon.

0.77
(b) Manganese.

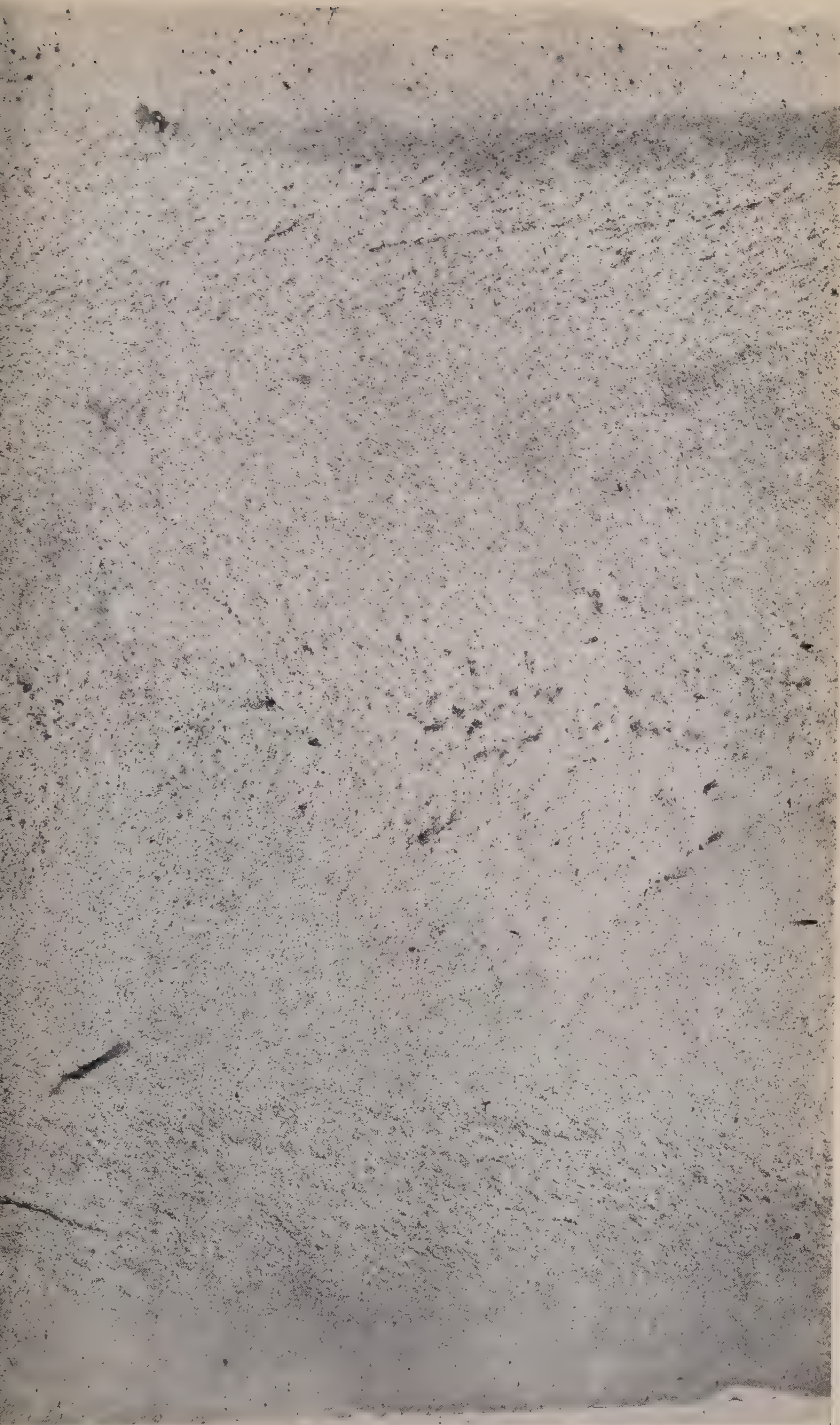
0.229
(c) Silicon.

0.038
(d) Sulphur.

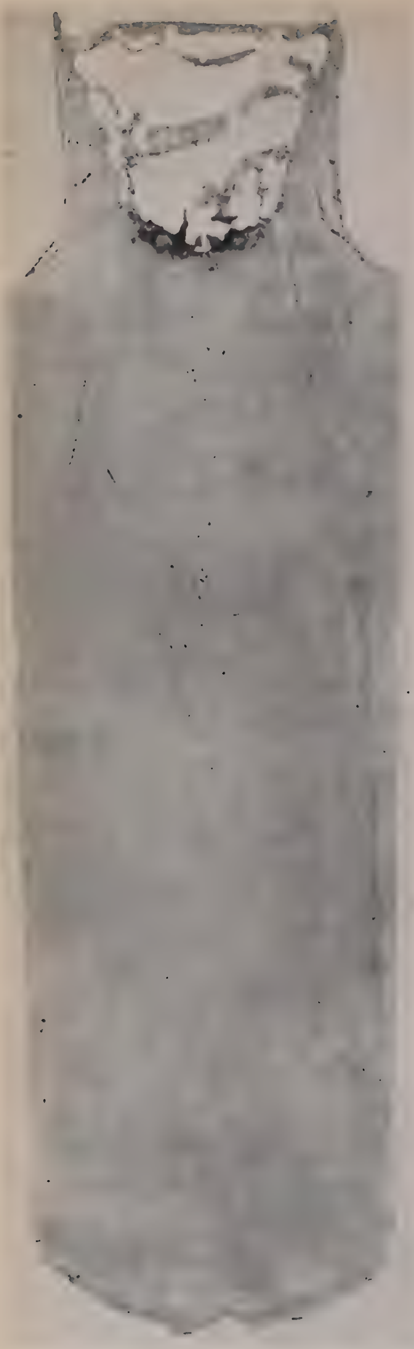
0.040
(e) Phosphorus.

(f) Brinell hardness.

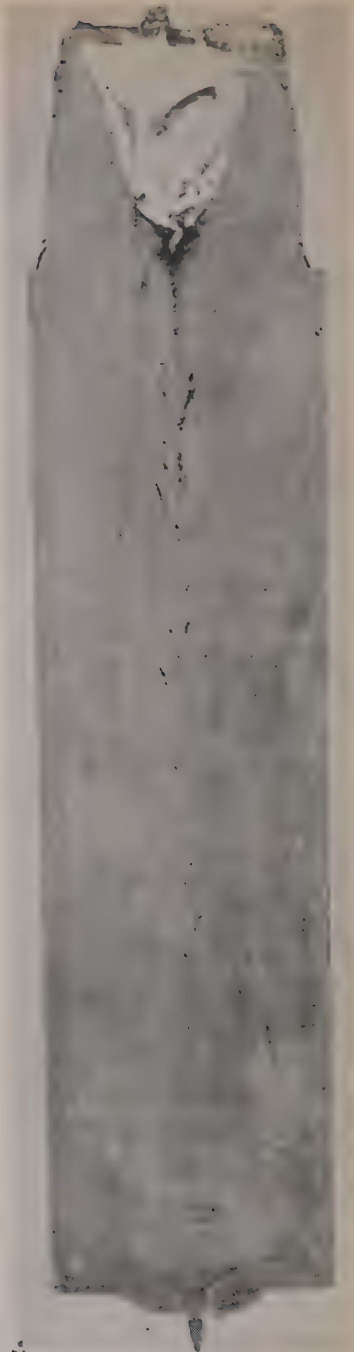
Example 6.—3-ton Ingot. Distribution of elements, and hardness.



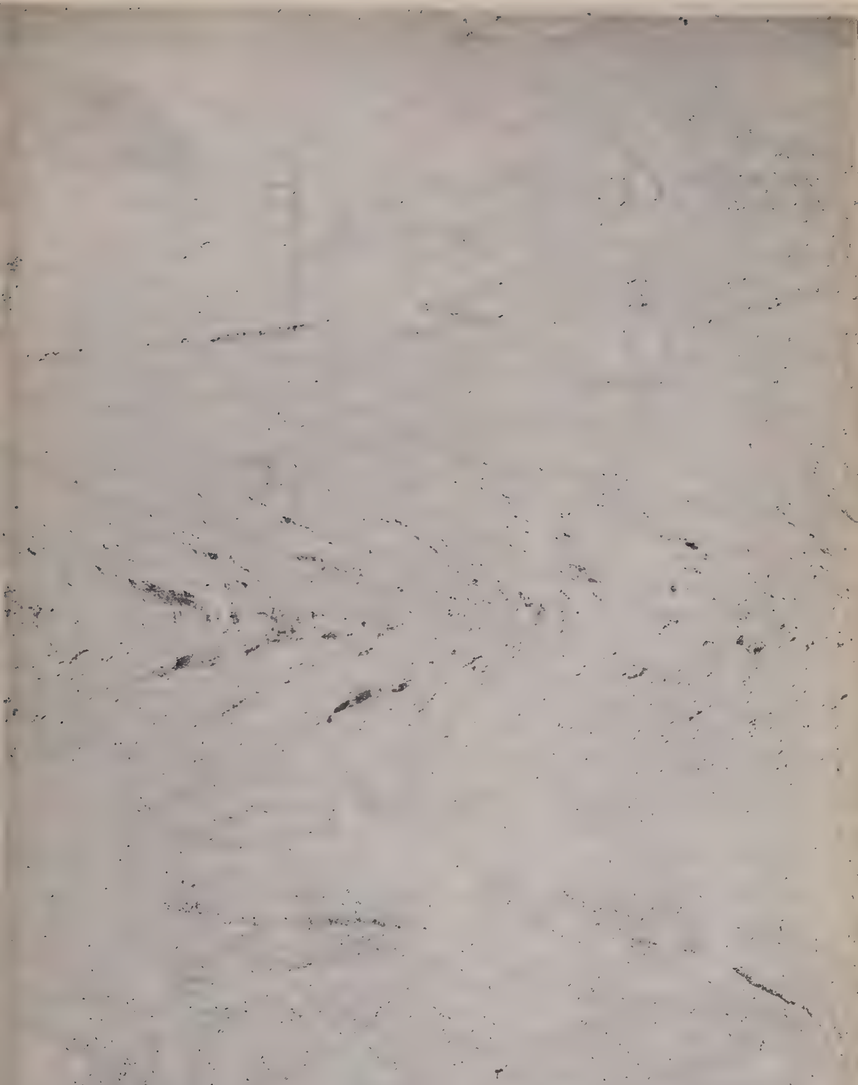
Example 5 *h*.—3-ton Ingot. Section of Sulphur print.



Example 5 g.—3-ton Ingot.
Sulphur print.

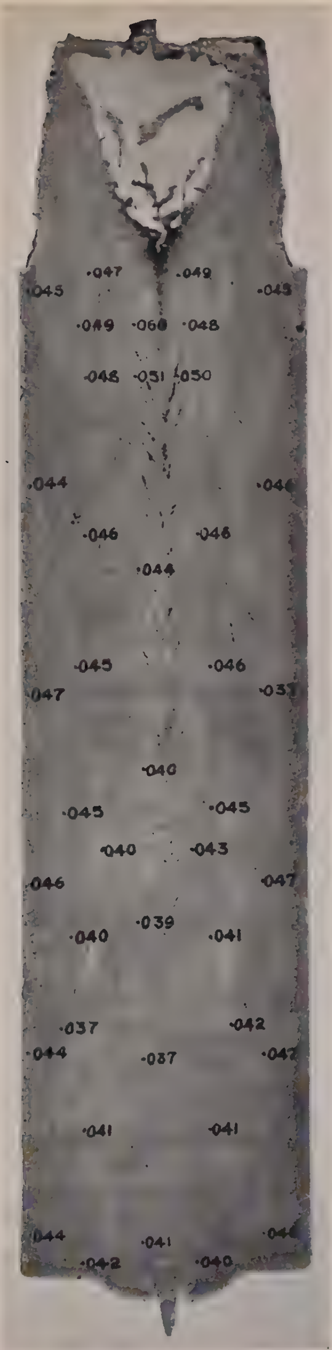


Example 6 g.—3-ton Ingot.
Sulphur print.

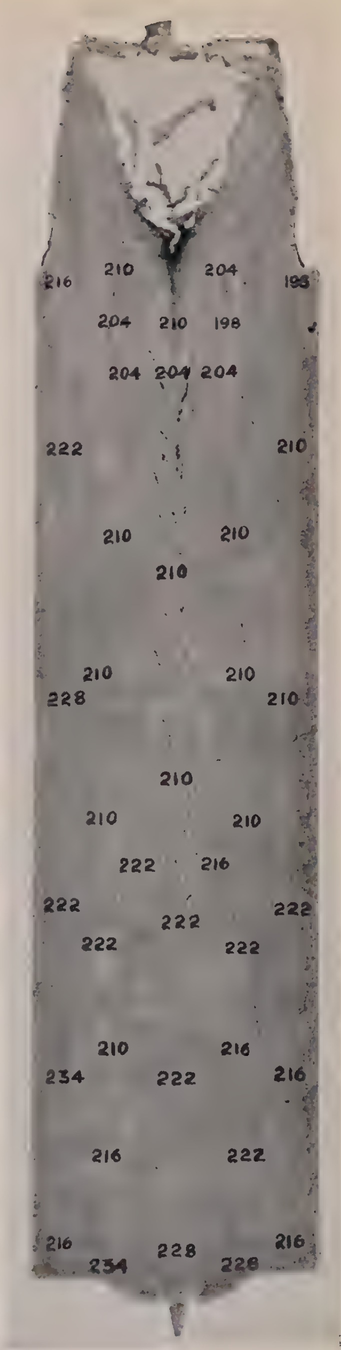


Example 6 *h*.—3-ton Ingot. Portion of Sulphur print.

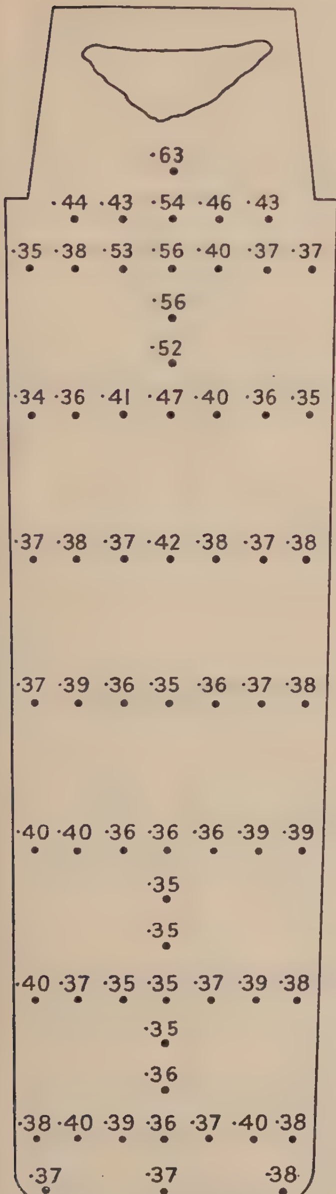
PLATE XIV.



0.040
(*e*) Phosphorus.



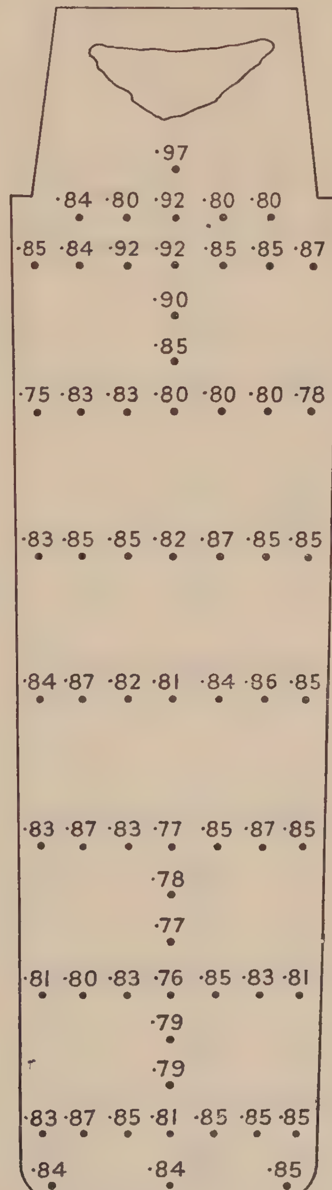
(*f*) Brinell hardness.



CARBON

Cast Analysis, 0·40.

a.

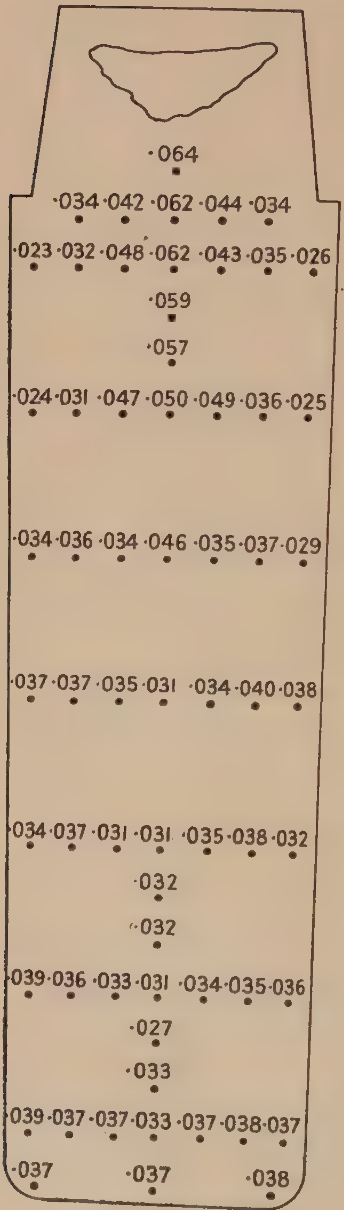


MANGANESE

Cast Analysis, 0·83.

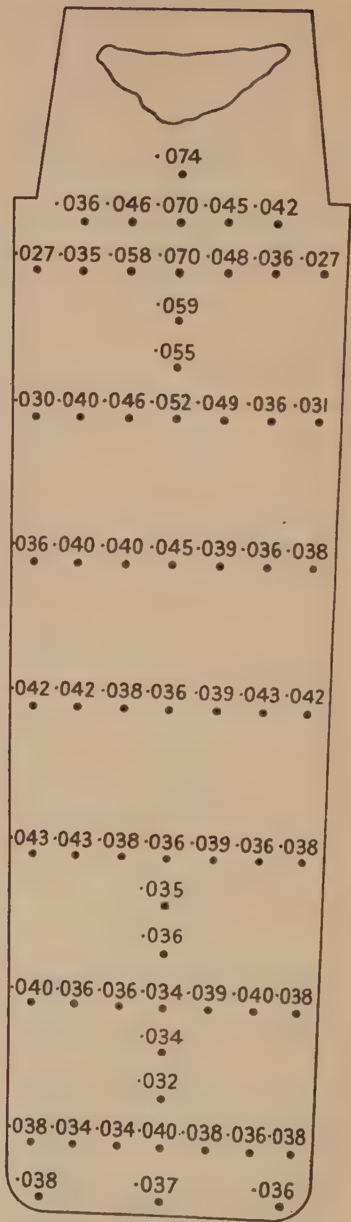
b.

EXAMPLE 7.—3¼-ton Ingot. Distribution of Elements.



SULPHUR

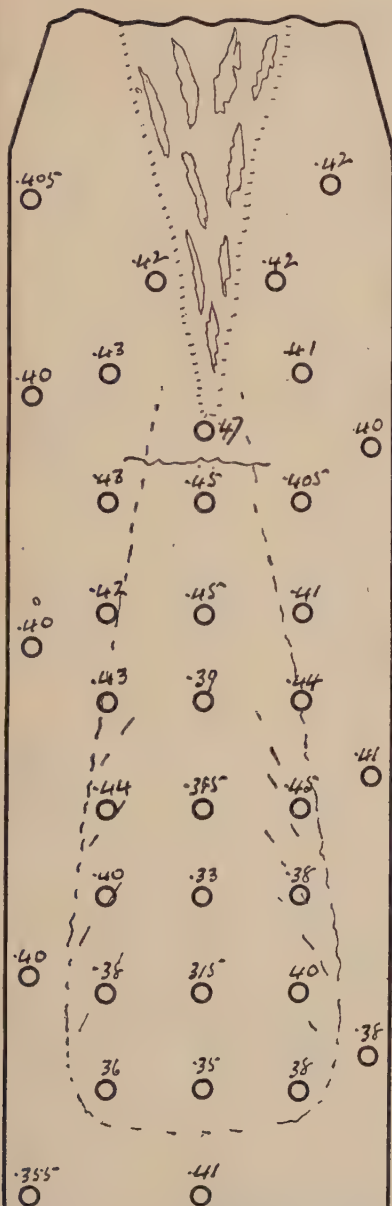
Cast Analysis, 0·034.
c.



PHOSPHORUS

Cast Analysis, 0·042.
d.

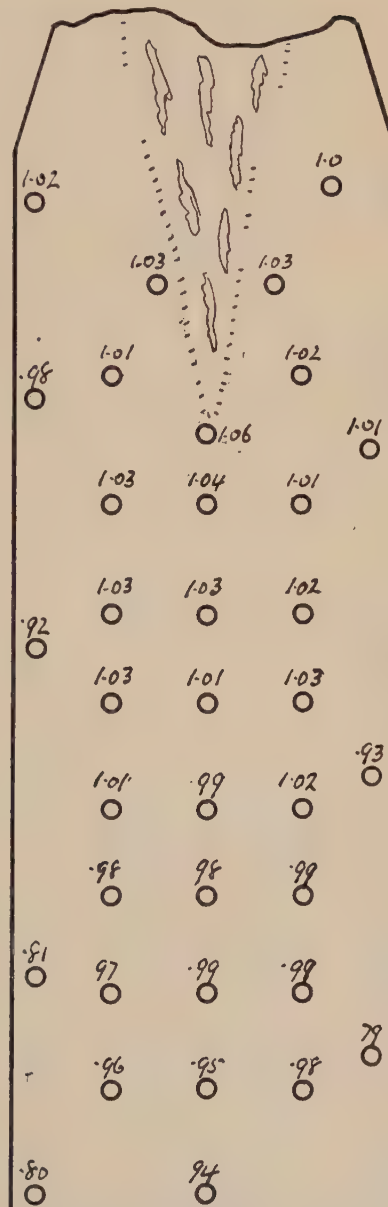
EXAMPLE 7.—3½-ton Ingot. Distribution of Elements.



CARBON

Cast Analysis, 0·39.

a.

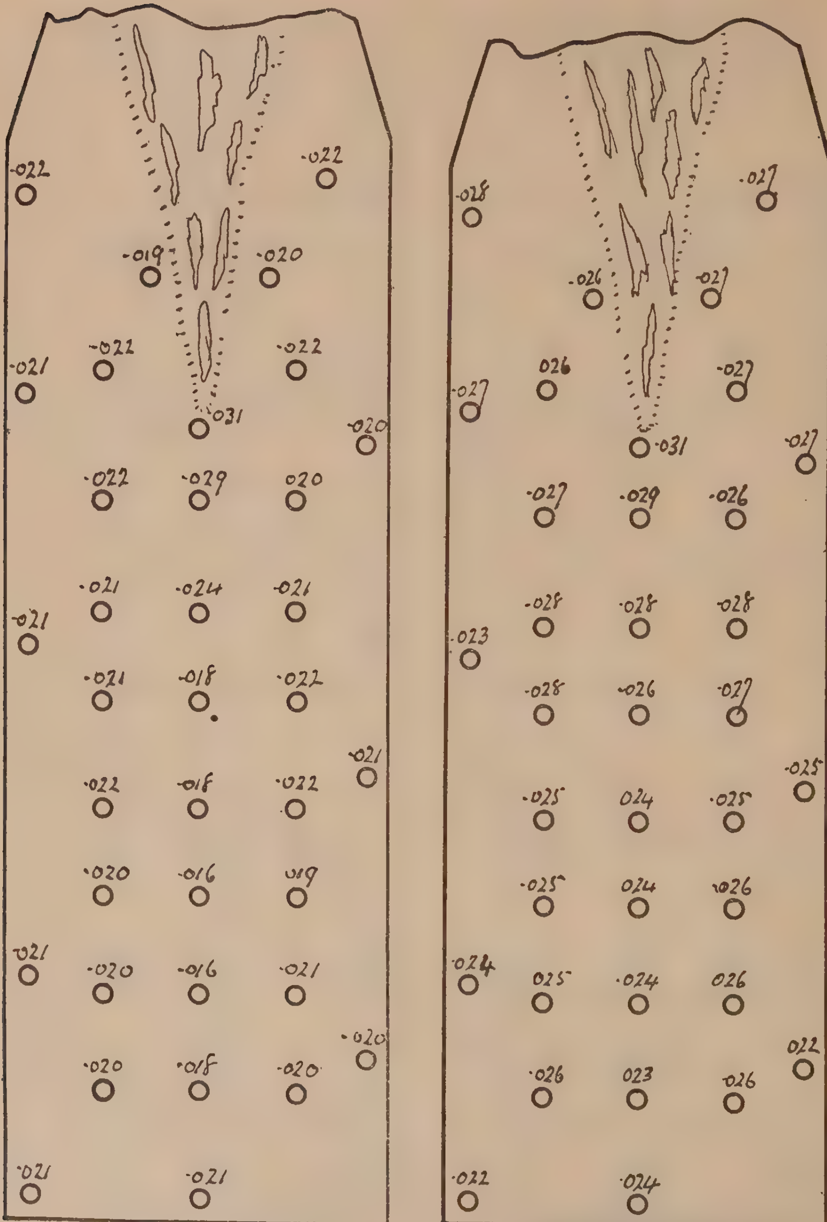


MANGANESE

Cast Analysis, 0·96.

b.

EXAMPLE 8.—8-ton Ingot. Distribution of Elements.



SULPHUR

Cast Analysis, 0·025.

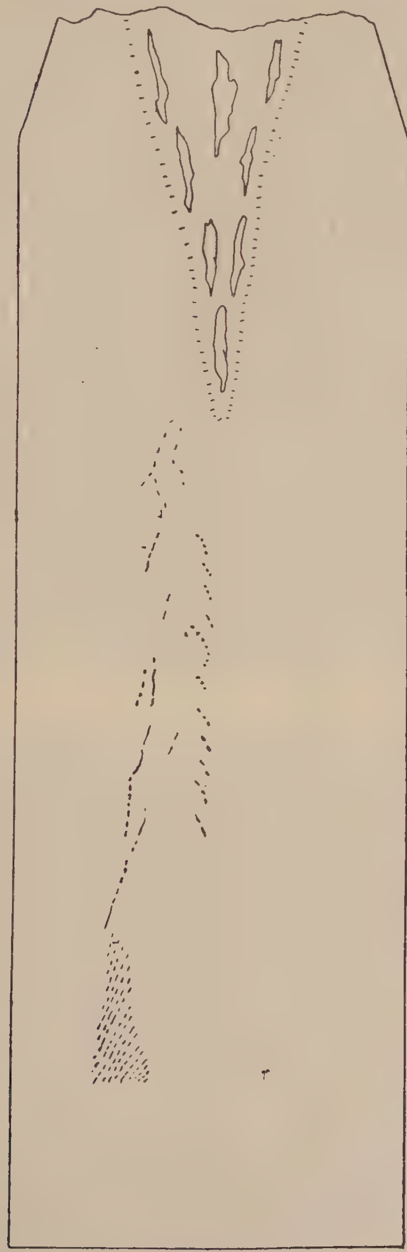
c.

PHOSPHORUS

Cast Analysis, 0·024.

d.

Example 8.—8-ton Ingot. Distribution of Elements.



SULPHUR GRAPH

e.

EXAMPLE 8.—8-ton Ingot. Half Surface shown.

CARBON

Cast Analysis, 0·21.

a.

SULPHUR

Cast Analysis, 0·027.

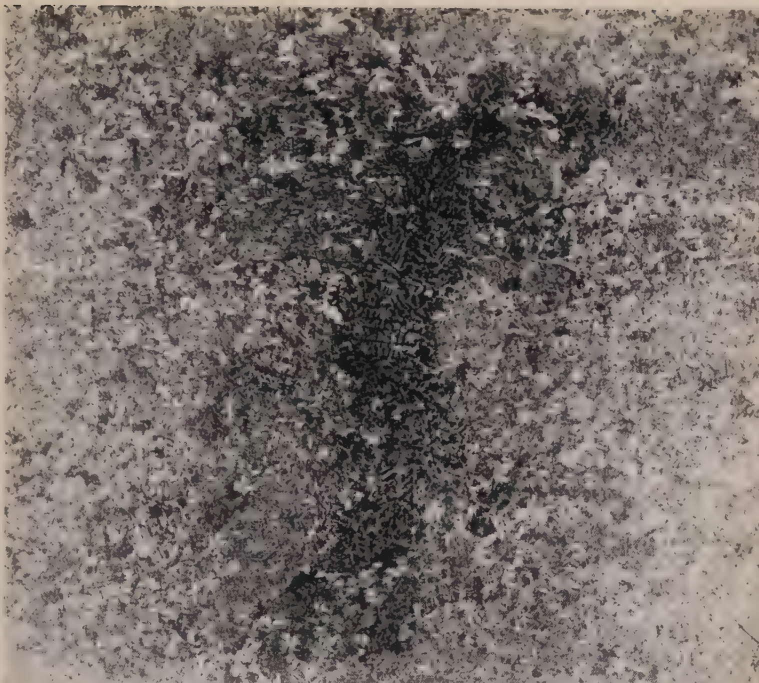
b.

PHOSPHORUS

Cast Analysis, 0·05.

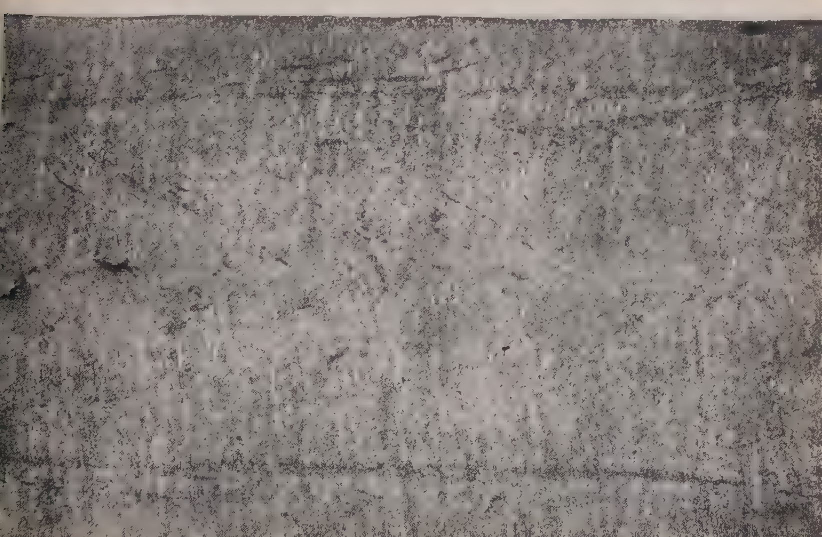
c.

Example 9.—8¼-ton Ingot Cast in Loam Mould. Distribution of Elements.



(f) Example of segregate existing in this ingot.

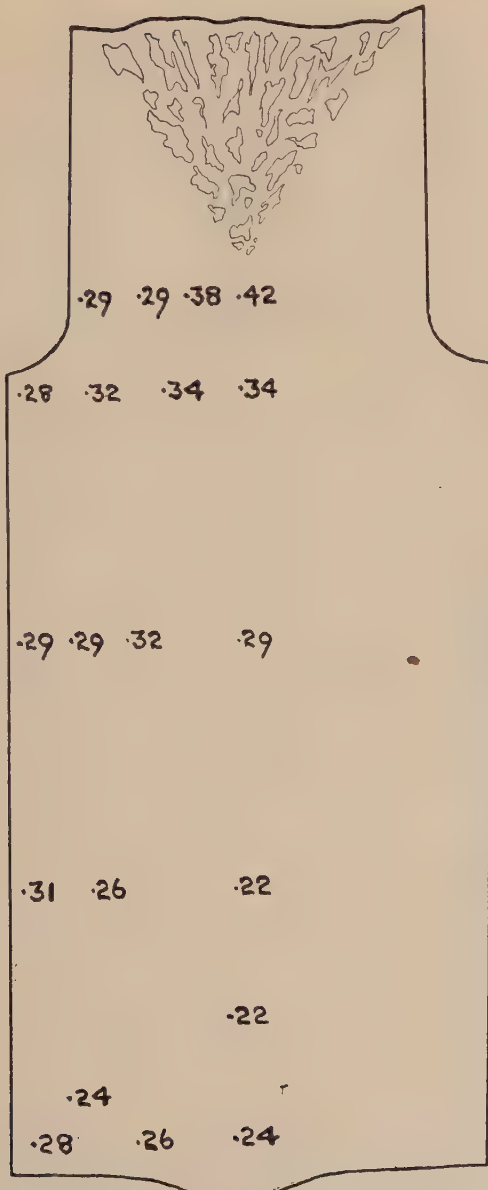
Example 9.—8¼-ton Ingot.



(e) Portion of etched surface.

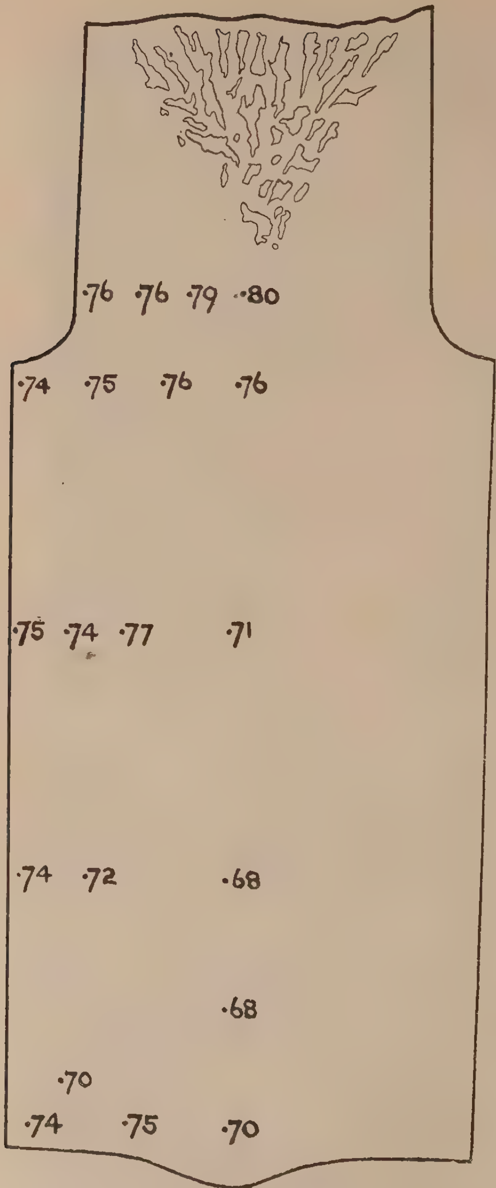
[To face p. 60

Example 10 *f*.—10½-ton Ingot. Sulphur print.



Cast Analysis, 0·30.

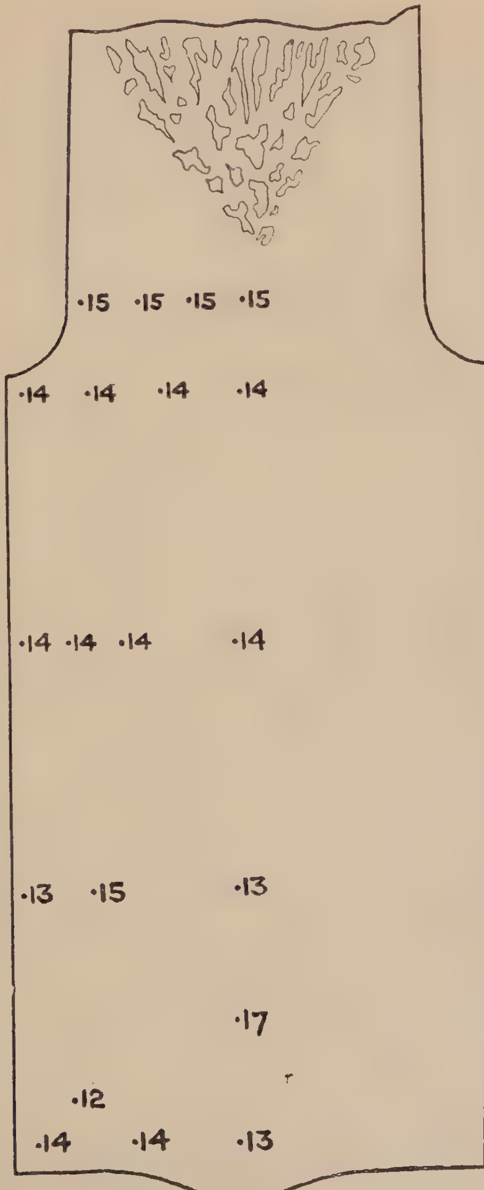
EXAMPLE 10*a*.—10½-ton Ingot. Distribution of Carbon.



MANGANESE

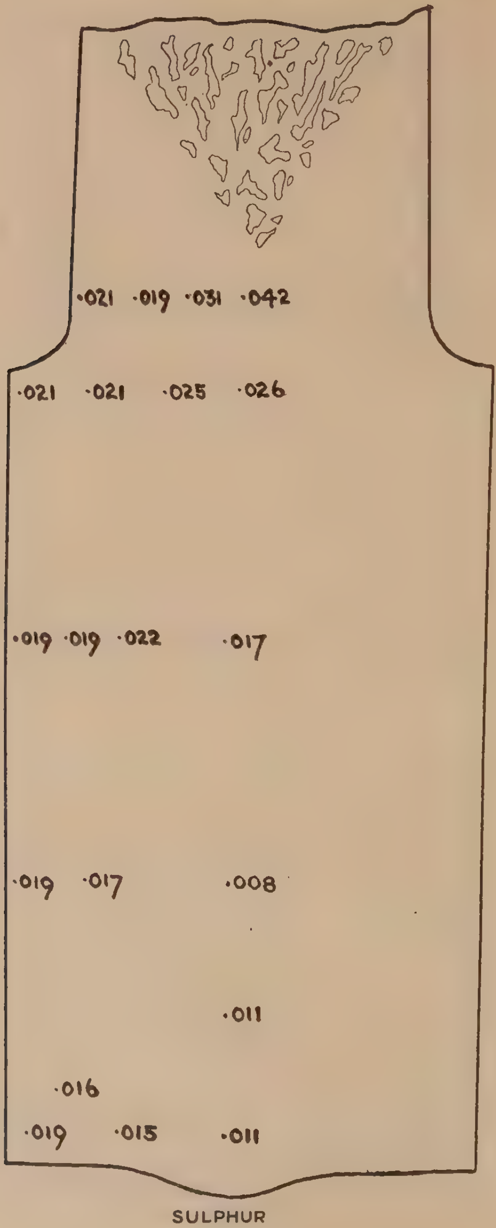
Cast Analysis, 0·74.

EXAMPLE 10 *b*.—10½-ton Ingot. Distribution of Manganese.



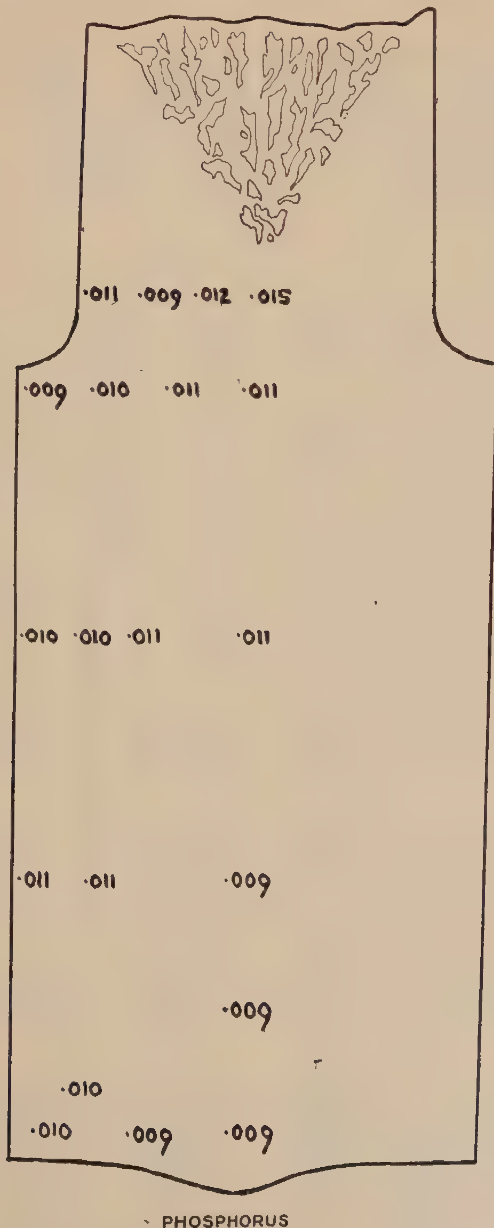
Cast Analysis, 0·13.

EXAMPLE 10*c*.—10½-ton Ingot. Distribution of Silicon.



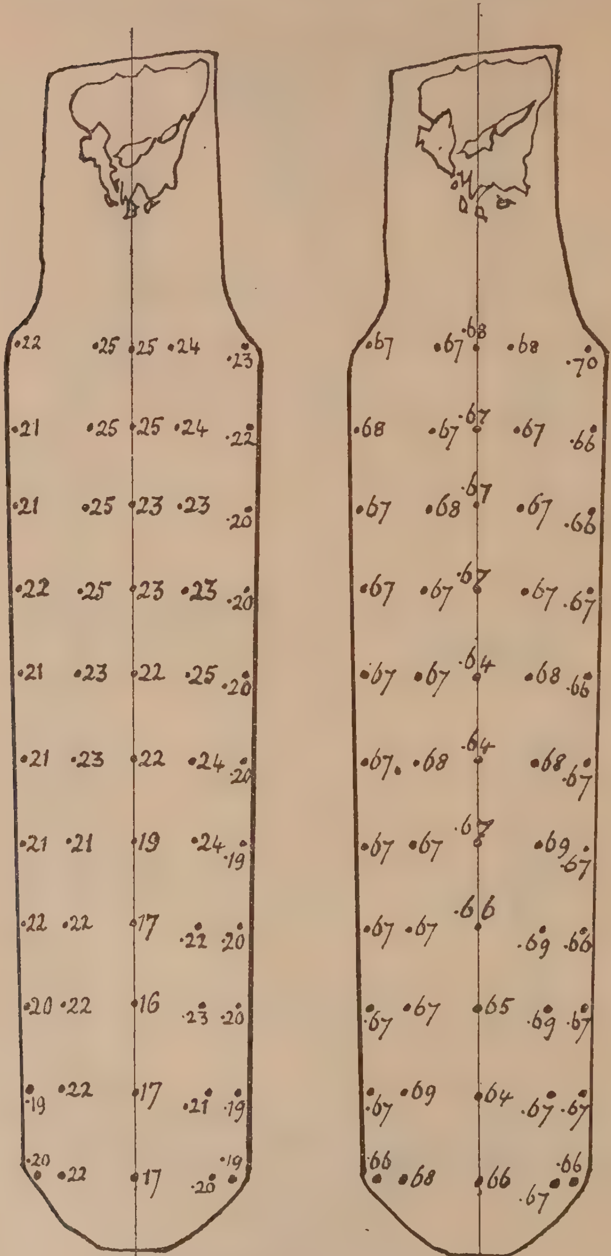
Cast Analysis, 0·017.

Example 10*d*.—10½-ton Ingot. Distribution of Sulphur.



Cast Analysis, 0·010.

EXAMPLE 10*e*.—$10\frac{1}{2}$-ton Ingot. Distribution of Phosphorus.



CARBON

Cast Analysis, 0·21.

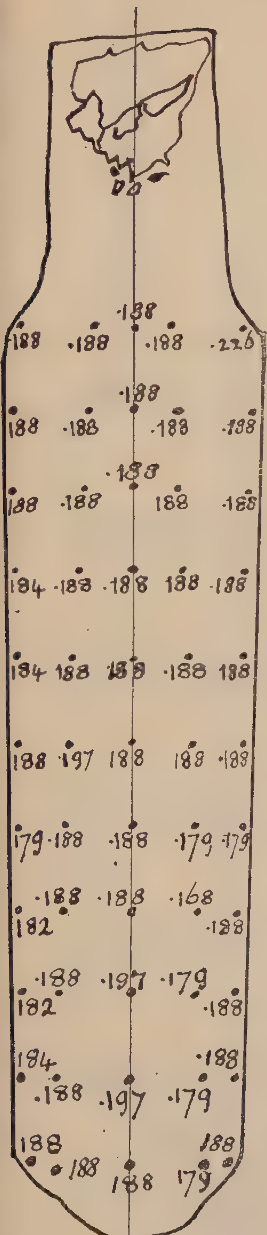
a.

MANGANESE

Cast Analysis, 0·66.

b.

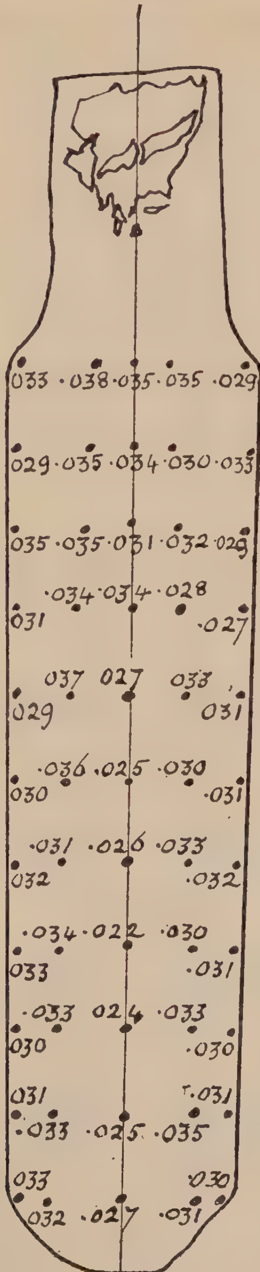
EXAMPLE 11.—20-ton Ingot. Distribution of Elements.



SILICON

Cast Analysis, 0·169.

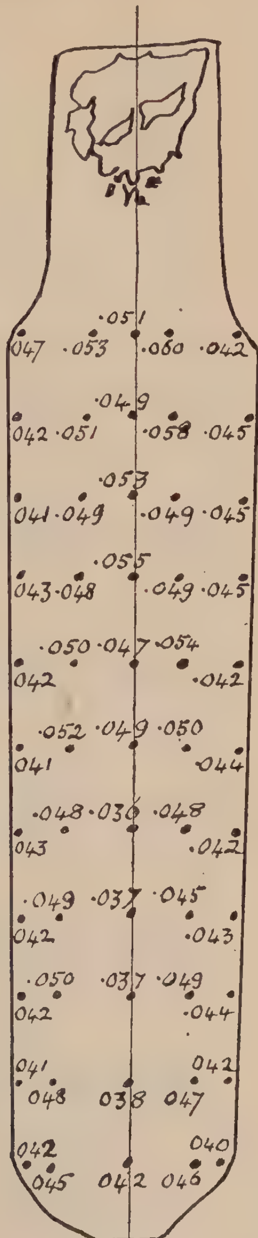
c.



SULPHUR

Cast Analysis, 0·032.

d.

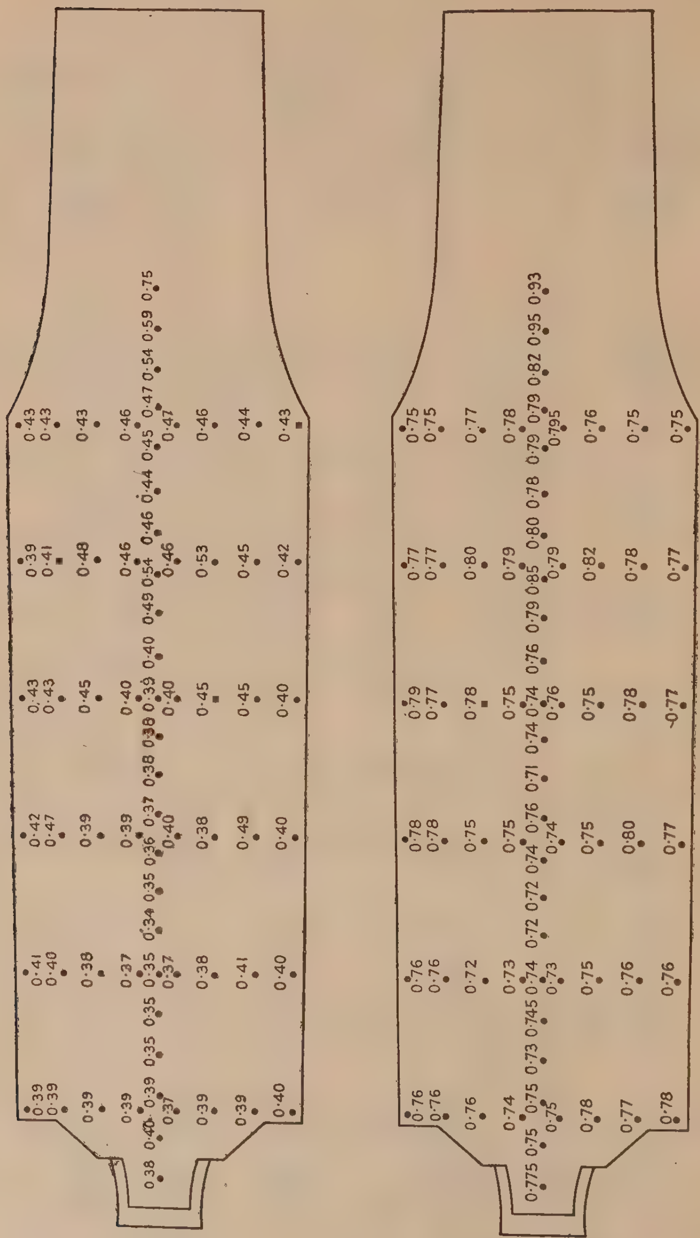


PHOSPHORUS

Cast Analysis, 0·040.

e.

EXAMPLE 11.—20-ton Ingot. Distribution of Elements.



CARBON

Cast Analysis, 0·44.

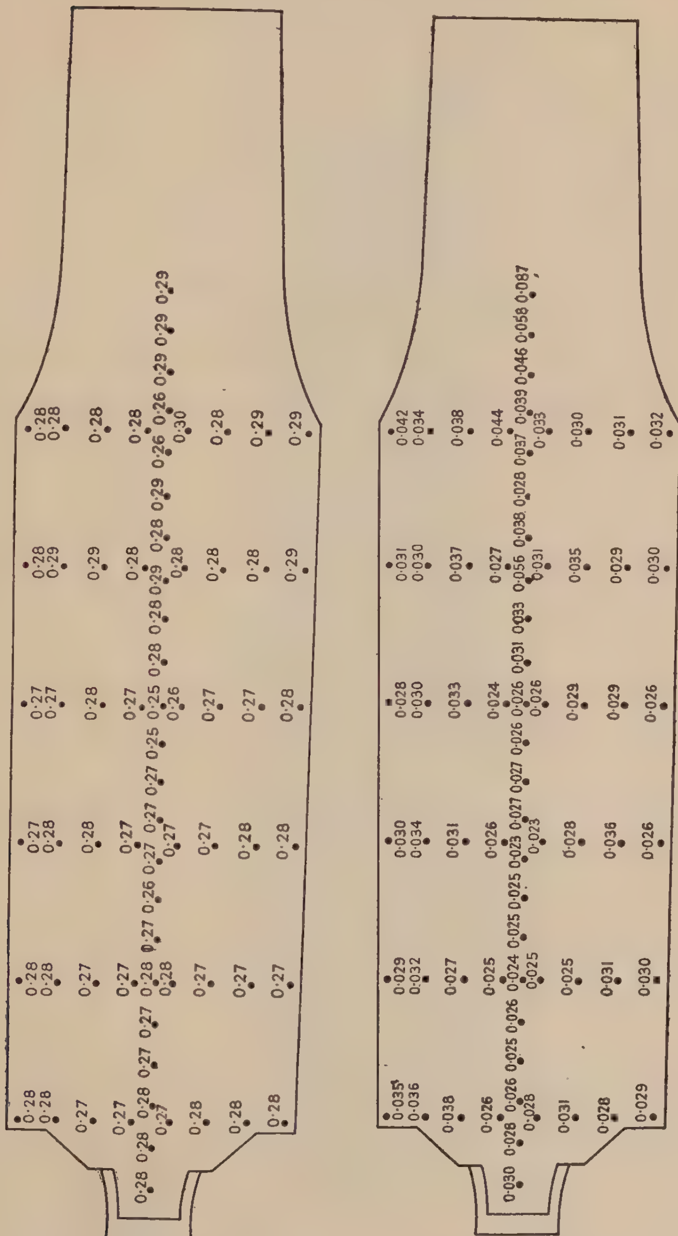
a.

MANGANESE

Cast Analysis, 0·78.

b.

EXAMPLE 12.—25-ton Ingot. Distribution of Elements.



SILICON

Cast Analysis, 0·29.

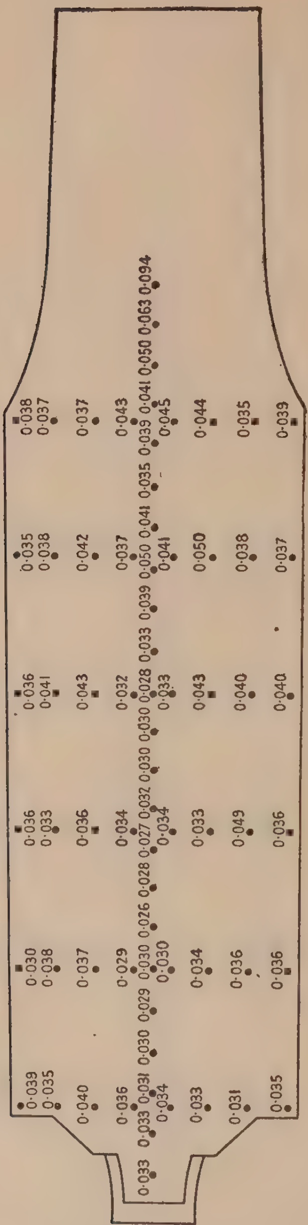
c.

SULPHUR

Cast Analysis, 0·033.

d.

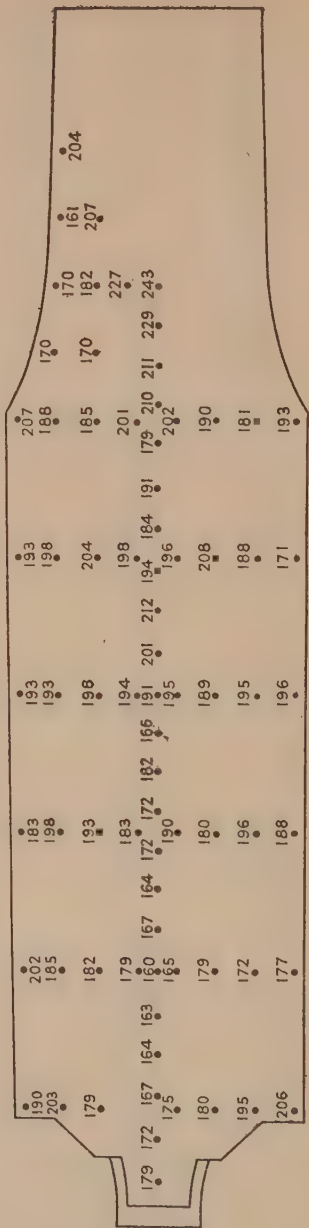
EXAMPLE 12.—25-ton Ingot. Distribution of Elements.



PHOSPHORUS

Cast Analysis, 0·042.

e.



BRINELL

f.

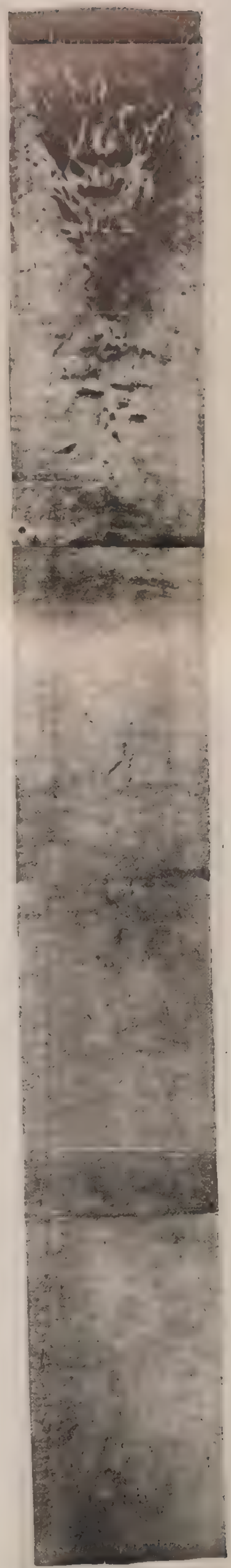
EXAMPLE 12.—25-ton Ingot. Distribution of Phosphorus and Hardness.

Example 11 *f*.—20-ton Ingot. Sulphur print.

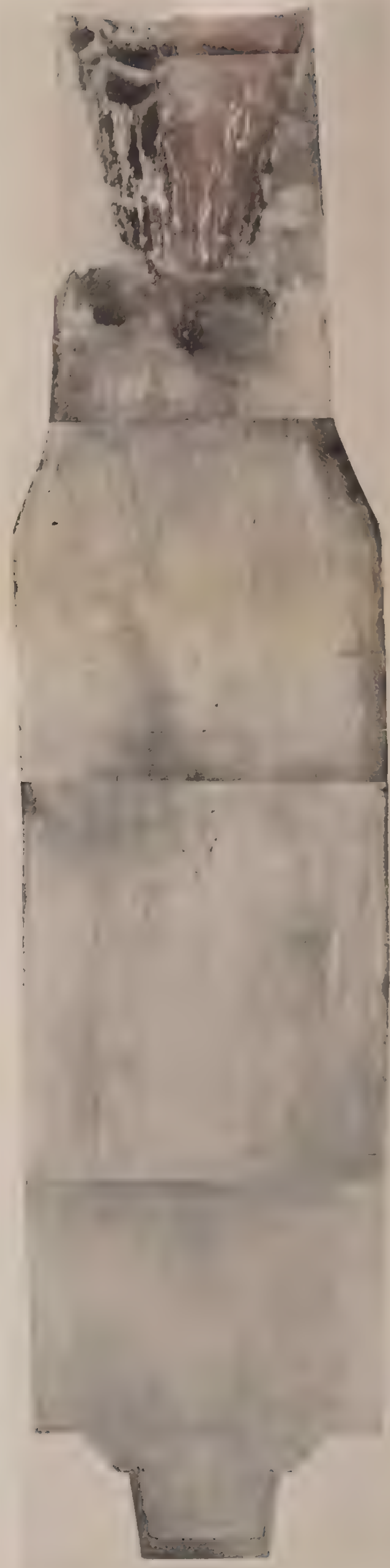
[*To face p.* 70

Example 12 h.—$24\frac{3}{4}$-ton Ingot. Portion of etched surface.

PLATE XIX



Example 9 *d.*—$8\frac{1}{4}$-ton Ingot.
Etched section.



Example 12 *g.*—$24\frac{3}{4}$-ton Ingot.
Etched surface.

Example 15 *f.* — 110-ton
Ingot. Sulphur print
of core of bloom.

silicon, sulphur, and phosphorus over the entire longitudinal half-section of the ingot. Example 4 *f* (Plate VIII.) is a reproduction of the sulphur print obtained from the same section, which again shows the zone of segregate intermediate between the outside of the ingot and the central axis, and also well-marked segregate along the axis.

Example 5.—An ingot cast in a chill rectangular mould. Weight, 2 tons 18 cwts. 2 qrs. Size, $23\frac{3}{4}$ in. × $17\frac{5}{8}$ in. at the top of the chill, $21\frac{1}{2}$ in. × $15\frac{1}{2}$ in. at the bottom; 5 feet 2 inches in chill. Top poured.

The steel was produced by the acid open-hearth process, and was of the following composition: Carbon 0·34, manganese 0·70, silicon 0·163, sulphur 0·049, phosphorus 0·039 per cent.

The charts for Example 5, marked *a*, *b*, *c*, *d*, and *e* respectively (Plate X.), show the results of the analyses at various points on the longitudinal section for carbon, manganese, silicon, sulphur, and phosphorus. Example 5 *f* shows the Brinell hardness numbers obtained at different points on the same section; Example 5 *g* (Plate XII.) is a reproduction of the sulphur print obtained from the section of this ingot, and Example 5 *h* (Plate XI.) is a portion of the same sulphur print reproduced on a somewhat larger scale. This ingot, too, shows a definitely marked segregation zone intermediate between the outside of the ingot and the central axis, while there are indications of well-marked segregation along the axis.

Example 6.—An ingot cast in a chill mould. Weight, 2 tons 18 cwts. Size, $20\frac{1}{2}$ inches wide at the top of the chill, $19\frac{1}{2}$ inches at the bottom; 5 feet 7 inches in chill. Top poured. This ingot was twelve-sided (concave).

The steel was manufactured by the acid open-hearth process, and was of the following composition: Carbon 0·60, manganese 0·77, silicon 0·229, sulphur 0·038, phosphorus 0·040 per cent.

The charts for Example 6, marked *a*, *b*, *c*, *d*, and *e* respectively (Plate XIV.), show the results of the analyses for carbon, manganese, silicon, sulphur, and phosphorus at different positions throughout the longitudinal half-section. Example 6 *f* shows the Brinell hardness numbers obtained at different points over the same section, and Example 6 *g* (Plate XII.) is a reproduction of the sulphur print obtained from this ingot section, a portion

of which is again reproduced on a larger scale in Example 6 *h* (Plate XIII.). The well-marked zone of segregation again appears intermediate between the outside and the central axis, whilst along the central axis there is likewise well-marked segregation.

Example 7.—An ingot cast in a chill mould. Weight, 3 tons 5 cwts. Size, 20 inches square at the top of the chill, 18 inches square at the bottom; 5 feet 6 inches in chill. Top poured.

The steel was manufactured by the basic open-hearth process, and had the following composition: Carbon 0·40, manganese 0·83, silicon 0·12, sulphur 0·034, phosphorus 0·042 per cent.

The charts for Example 7, marked *a*, *b*, *c*, and *d* respectively (pp. 55, 56), show the results of the analyses for the carbon, manganese, sulphur, and phosphorus content at the various positions in the longitudinal half-section, but neither a sulphur print, silicon chart, nor hardness determinations were available in this case.

Example 8.—An ingot cast in a split chill mould. Weight, 8 tons. Size, 3 ft. 4 in. × 2 ft. 1 in. at the top of the chill, 3 ft. 4 in. × 2 ft. 1 in. at the bottom. Top poured.

The steel was produced by the basic open-hearth process, and had the following composition: Carbon 0·39, manganese 0·96, silicon 0·08, sulphur 0·025, phosphorus 0·024 per cent.

The charts for Example 8, marked *a*, *b*, *c*, and *d* respectively (pp. 57, 58), show the results of the analyses for carbon, manganese, sulphur, and phosphorus at different points in the longitudinal half-section of this ingot; whilst Example 8 *e* (p. 59) is a reproduction of the salient features of the sulphur print. Here again there is an intermediate zone of segregate, and decided segregate along the central axis.

Example 9.—An ingot cast in a round loam mould. Weight, 8 tons 5 cwts. (manufactured abroad). Size, 15 feet 7½ inches in length, 22 inches in diameter. Top poured.

The steel was manufactured by the basic open-hearth process, and had the following composition: Carbon 0·21, manganese 0·51, silicon 0·04, sulphur 0·027, phosphorus 0·059 per cent.

The charts for Example 9, marked *a*, *b*, and *c* respectively (p. 60), show the results of the analyses for carbon, sulphur, and phosphorus at different points over the longitudinal half-section. Example 9 *d* (Plate XIX.) is a photograph of the section of the ingot after etching with nitric acid, and Example 9 *e* (Plate XV.) shows on a larger scale a part of the same

section. There are well-marked segregation zones of a similar nature to those found in the case of Example 1 (Plate V.), which run very closely towards the outer surface of the ingot, and others are seen along, and in proximity to, the central axis of this ingot.

The segregate in this case was, in fact, so clearly defined as to appear as a distinct and separate constituent, clearly visible in the photograph of the etched surface in Example 9*f* (Plate XV.). The opportunity was therefore taken to make a more intimate examination of these segregates; patches were carefully chiselled out and the analysis was obtained as follows:

	Segregated Area. Per Cent.	Mean Composition. Per Cent.
Carbon	0·36	0·21
Manganese	0·575	0·51
Silicon	0·05	0·04
Sulphur	0·105	0·027
Phosphorus	0·220	0·059
Nickel	...	
Chromium	Nil	
Tungsten	,,	
Molybdenum	,,	
Vanadium	,,	
Cobalt	,,	

It will be seen that there is considerable segregation of carbon, sulphur, and phosphorus as compared with the analysis of the test sample, also a slight increase in the manganese content, but the silicon is the same within limits covered by errors in analysis.

Example 10.—An ingot cast in a chill octagon mould. Weight, 10 tons 10 cwts. Top poured.

It was cast from steel made by the electric steel-making process (basic bottom), and had the following composition: Carbon 0·30, manganese 0·74, silicon 0·13, sulphur 0·017, phosphorus 0·010 per cent.

The charts for Example 10, marked *a*, *b*, *c*, *d*, and *e* respectively (pp. 61–65), show the results of the analyses for carbon, manganese, silicon, sulphur, and phosphorus over the longitudinal half-section from the central axis to the outside of the ingot. Example 10*f* (Plate XVI.) is a reproduction of the sulphur print. Here again it will be seen that the zones of segregate intermediate between the outside of the ingot and the central core are very apparent.

Example 11.—An ingot cast in a chill octagon mould. Weight, 20 tons. Size, 37 inches at the top of the chill, 35 inches at the bottom; 120 inches in chill. Top poured.

The steel was manufactured by the acid open-hearth process, and was of the following composition: Carbon 0·21, manganese 0·66, silicon 0·169, sulphur 0·032, phosphorus 0·040 per cent.

The charts for Example 11, marked *a*, *b*, *c*, *d*, and *e* respectively (pp. 66, 67), show the results of the analyses for carbon, manganese, silicon, sulphur, and phosphorus over the complete longitudinal half-section of the ingot. Example 11*f* (Plate XVII.) is a sulphur print of the sectioned surface.

Example 12.—An ingot cast in a chill octagon mould. Weight, 24 tons 17 cwts. 1 qr. Size, 43 inches at the top of the chill, 40 inches at the bottom. Top poured.

The steel was manufactured by the acid open-hearth process, and was of the following composition: Carbon 0·44, manganese 0·78, silicon 0·29, sulphur 0·033, phosphorus 0·042 per cent.

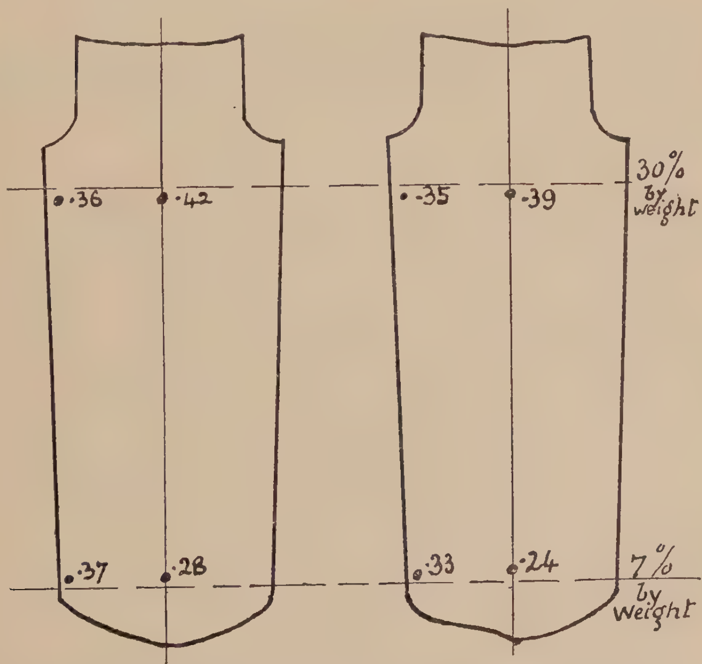
The charts for Example 12, marked *a*, *b*, *c*, *d*, and *e* respectively (pp. 68–70), show the results of the analyses for carbon, manganese, silicon, sulphur, and phosphorus over the complete longitudinal half-section. Example 12*f* shows the Brinell hardness numbers obtained over the entire section, whilst Example 12*g* (Plate XIX.) is a photographic reproduction of the result produced by etching the polished surface. Here again, besides the segregated area along the central core, zones of segregated material exist intermediate between the outside of the ingot and the central core. It will be observed how these zones of segregate are nearer together in the upper portion of the ingot than in the lower portion. Example 12*h* (Plate XVIII.) shows a larger view of a section of this etching.

For the purpose of making the data in the Report more complete as regards Example 12 *g*, careful investigation was made of the nature of the segregates in the region marked *G* to *F* (see Fig. 5, p. 91). The section of the ingot was repolished and lightly etched to disclose exactly the position of the segregate in this area. With a fine pneumatic chisel the actual segregates were then very painstakingly cut out of the steel, washed with ether and analysed, with the following result:

	Segregated Area. Per Cent.	Mean Composition. Per Cent.
Carbon	0·50	0·44
Manganese	0·82	0·78
Silicon	0·305	0·29
Sulphur	0·057	0·033
Phosphorus	0·066	0·042

It will be seen that the highly segregated area consists of material of greater concentration in carbon, sulphur, and phosphorus, the manganese and silicon remaining reasonably normal. In considering these figures it should be borne in mind that the segregates were isolated with the least possible amount of adjacent material.

Example 13.—Two ingots cast in chill octagon moulds. Weight, 54 tons each. Top poured.



Example 13.—Two 54-ton Ingots. Distribution of Carbon.

These two ingots are included as examples since, whilst it is only possible to present somewhat scanty information, that information is of a determining kind. It consists of the carbon content at critical points in the ingots, as will be seen in the illustration, Example 13.

Example 14.—A bloom produced from an ingot cast in an octagon chill iron mould. Weight, 64 tons. Size, across the

flats, 4 feet $11\frac{1}{2}$ inches at the top, 4 feet $7\frac{1}{2}$ inches at the bottom; 13 feet 5 inches in chill. Top poured.

The steel was manufactured by the acid open-hearth process, and was of the following composition: Carbon 0·40, manganese 0·63, silicon 0·16, sulphur 0·035, phosphorus 0·038 per cent.

The charts for Example 14, marked *a*, *b*, *c*, *d*, and *e* respectively (pp. 78–82), show the results of the analyses for carbon, manganese, silicon, sulphur, and phosphorus throughout the section of the ingot, after the removal of the top and bottom end discards. Discs from the top and bottom of the bloom have been examined in a similar way, and the results are also given in the charts.

Example 15.—An ingot cast in an octagon chill mould. Weight, 110 tons. Size, $82\frac{3}{4}$ inches at the top of the chill, 71 inches at the bottom; 143 inches in chill. Top poured.

The steel was produced by the acid open-hearth process, and was of the following composition: Carbon 0·27, manganese 0·715, silicon 0·244, sulphur 0·033, phosphorus 0·024 per cent.

This ingot was reheated and bloomed, the length of the parallel portion which previously constituted the chill portion of the ingot becoming 186 inches and the diameter 68 inches. The feeder head was then cut off (17·5 per cent.), the bottom portion cut off (3·5 per cent.), and the bloom was trepanned, yielding a core 24 inches in diameter. This core was then sectioned, and the charts for Example 15, marked *a*, *b*, *c*, *d*, and *e* respectively (pp. 83–85), show a statement of the analyses indicating the distribution of the several elements, carbon, manganese, silicon, sulphur, and phosphorus, throughout the entire length of the bloom. In Example 15 *f* (Plate XIX.) will be found a reproduction of a sulphur print taken from the section of the core.

Example 16.—An ingot cast in an octagon chill mould. Weight, 172 tons. Size across the flats, 6 feet 4 inches at the top of the chill, 6 feet 7 inches at the bottom; 17 feet in chill. Top poured.

The steel was manufactured by the acid open-hearth process, and was of the following composition: Carbon 0·32, manganese 0·79, silicon 0·13, sulphur 0·027, phosphorus 0·033 per cent. (Four furnaces were used. This analysis is the mean of the four charges cast simultaneously.) After removal of the feeder head and the bottom portion of the ingot, the core was trepanned and

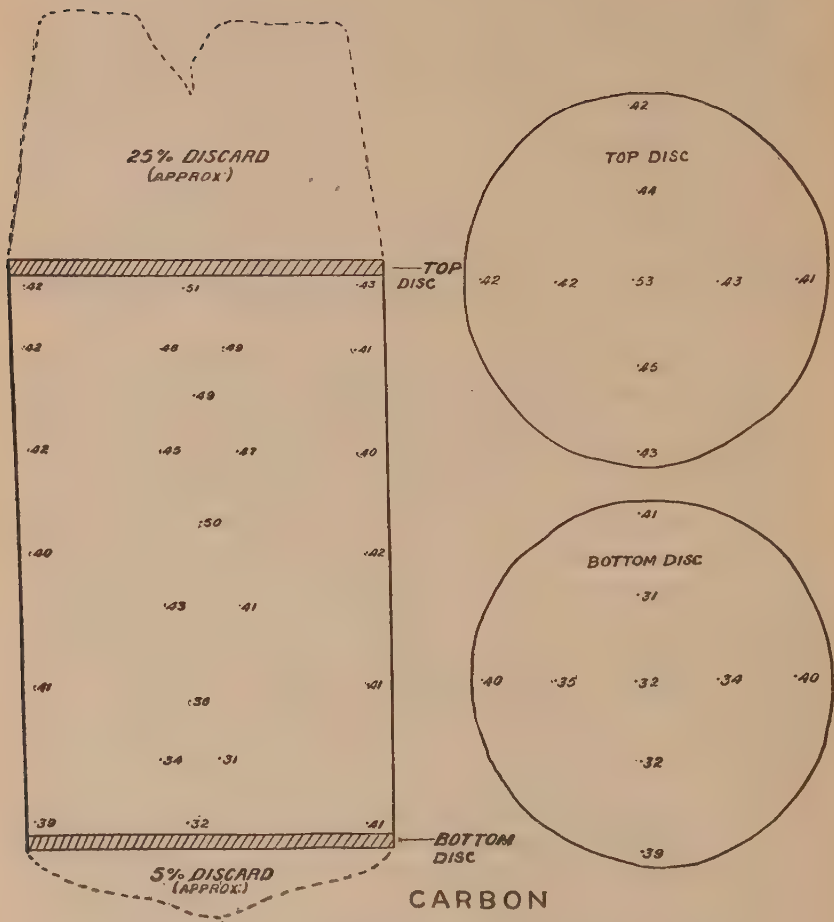
then sectioned, and analyses were made at numerous points. A disc was also removed from each end of the chill portion of the ingot, and the analyses were taken on samples prepared radially.

The charts for Example 16, marked *a*, *b*, *c*, *d*, and *e* respectively (pp. 86–90), show the results of the analyses for carbon, manganese, silicon, sulphur, and phosphorus over the longitudinal half-section of the core, and over the transverse sections taken from the top and bottom of the chill.

A reference to the data supplied for the several examples will indicate that in most instances fairly complete analyses are given for the different portions of each ingot, which sufficiently indicate the general degree of heterogeneity encountered within the mass.

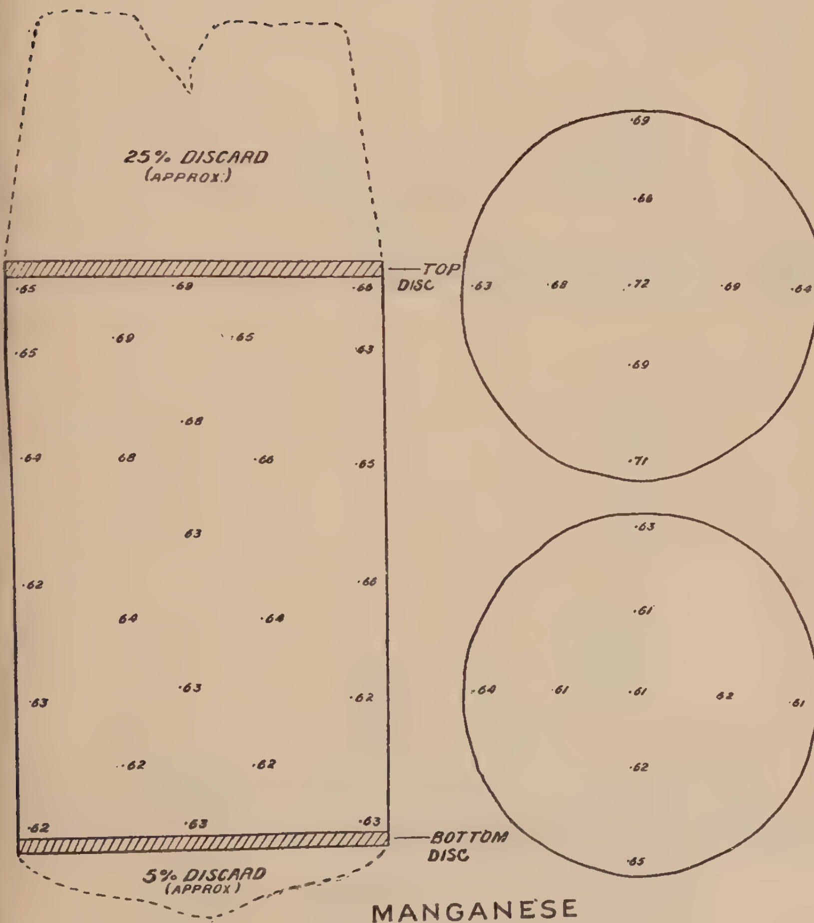
A comparison of the whole of the data is simplified by the use of reference points in the ingot, and this has been attempted in Fig. 5 (p. 91), a diagrammatic section of a typical ingot with seven such points arbitrarily fixed and marked *A*, *B*, *C*, *D*, *E*, *F*, and *G*. *A* is selected to indicate the average composition in the rapidly frozen outer portions. It has been found that the steel in the position thus selected at the outside represents more nearly than any other portion of the ingot the original composition of the liquid steel. The position *B* was chosen because it is almost always the purest portion of the ingot, *i.e.* the position where the percentages of all the segregating elements are lowest. The positions *C*, *D*, and *E*, together with the before-mentioned position *B*, represent the composition at various positions in succession along the axis of the ingot, it being understood that the position *D* is within the usable portion of the ingot. The positions *F* and *G* have been selected as being in the zone of segregated material which generally lies between the outside of the ingot and the central core. In studying the figures obtained at these several points, it should be borne in mind that in a measure they have not been regarded as fixed points, but as somewhat movable, according to the disclosure of the heterogeneity which they are designed to indicate.

In Tables II., III., IV., V., and VI. (pp. 92–94) will be found the percentage composition for the elements carbon, manganese,



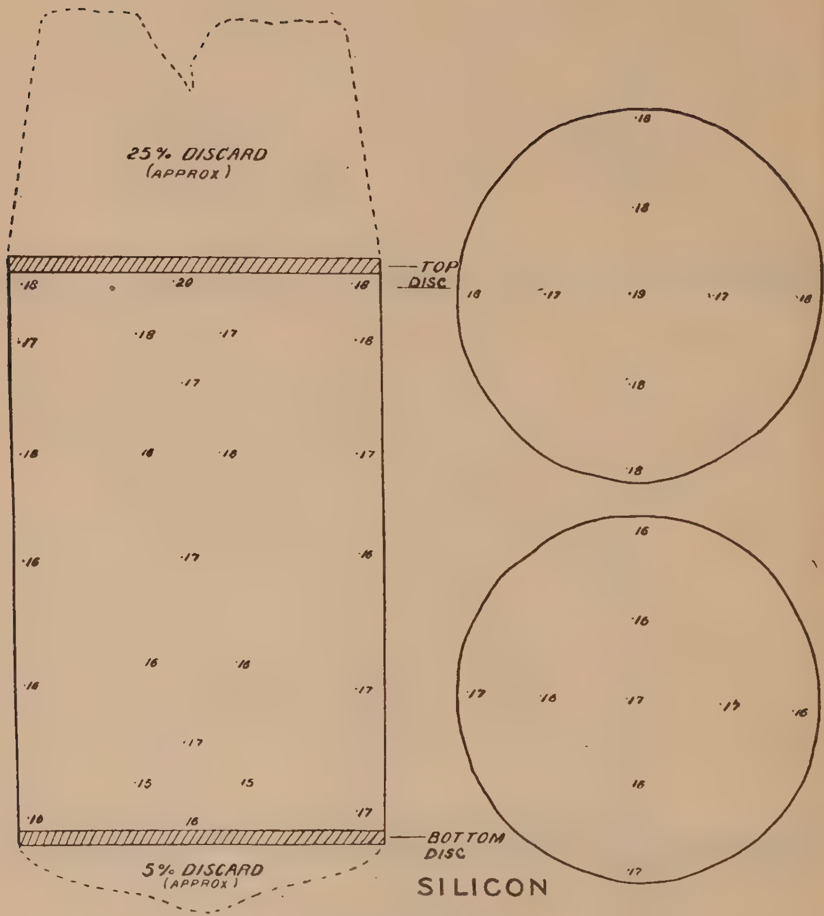
Cast Analysis, 0·40.

EXAMPLE 14*a*.—64-ton Ingot. Distribution of Carbon.



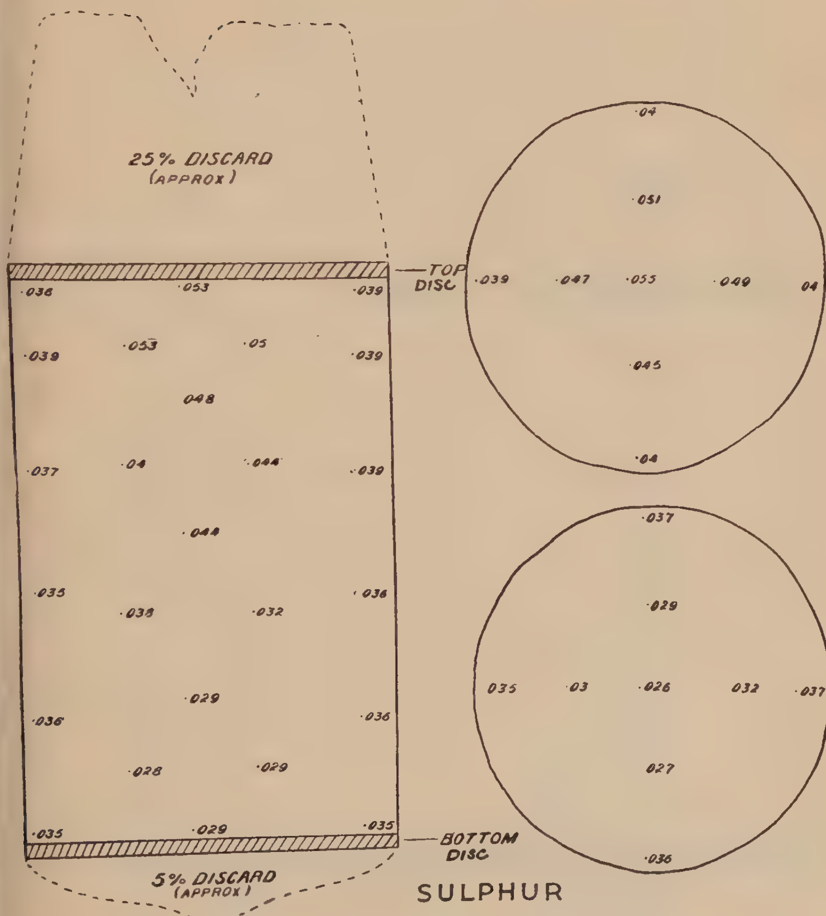
Cast Analysis, 0·63.

Example 14 *b*.—64-ton Ingot. Distribution of Manganese.



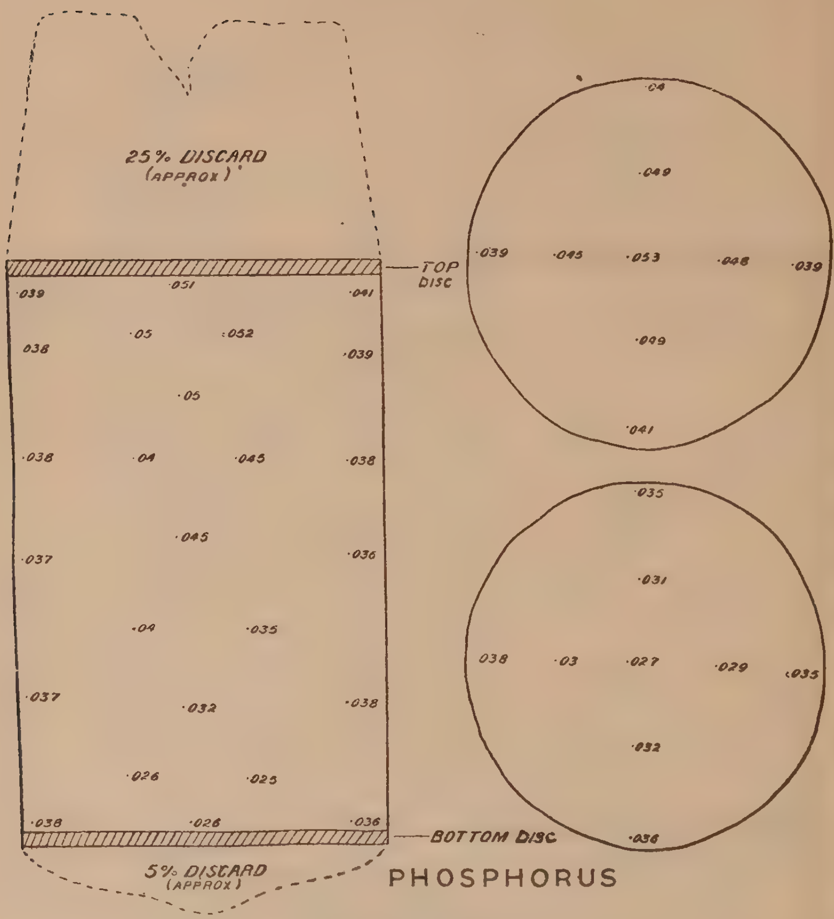
Cast Analysis, 0·16.

EXAMPLE 14c.—64-ton Ingot. Distribution of Silicon.



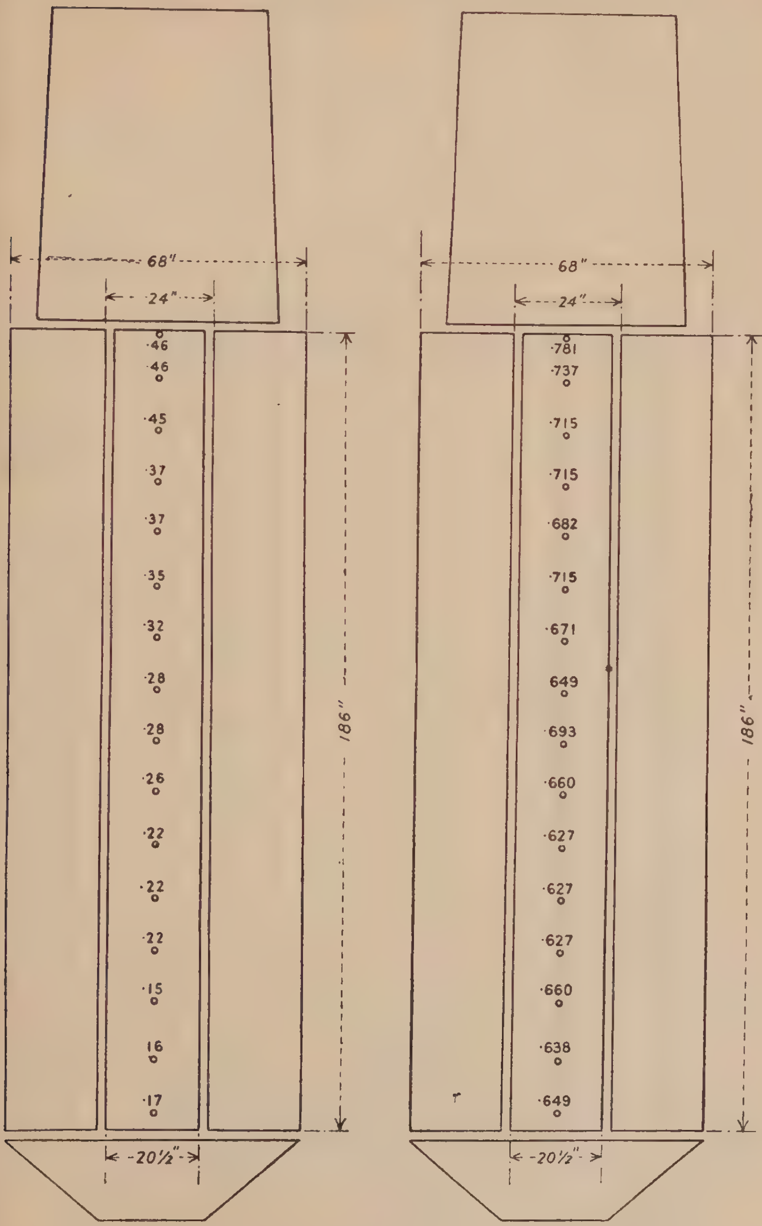
Cast Analysis, 0·035.

EXAMPLE 14 *d*.—64-ton Ingot. Distribution of Sulphur.



Cast Analysis, 0·038.

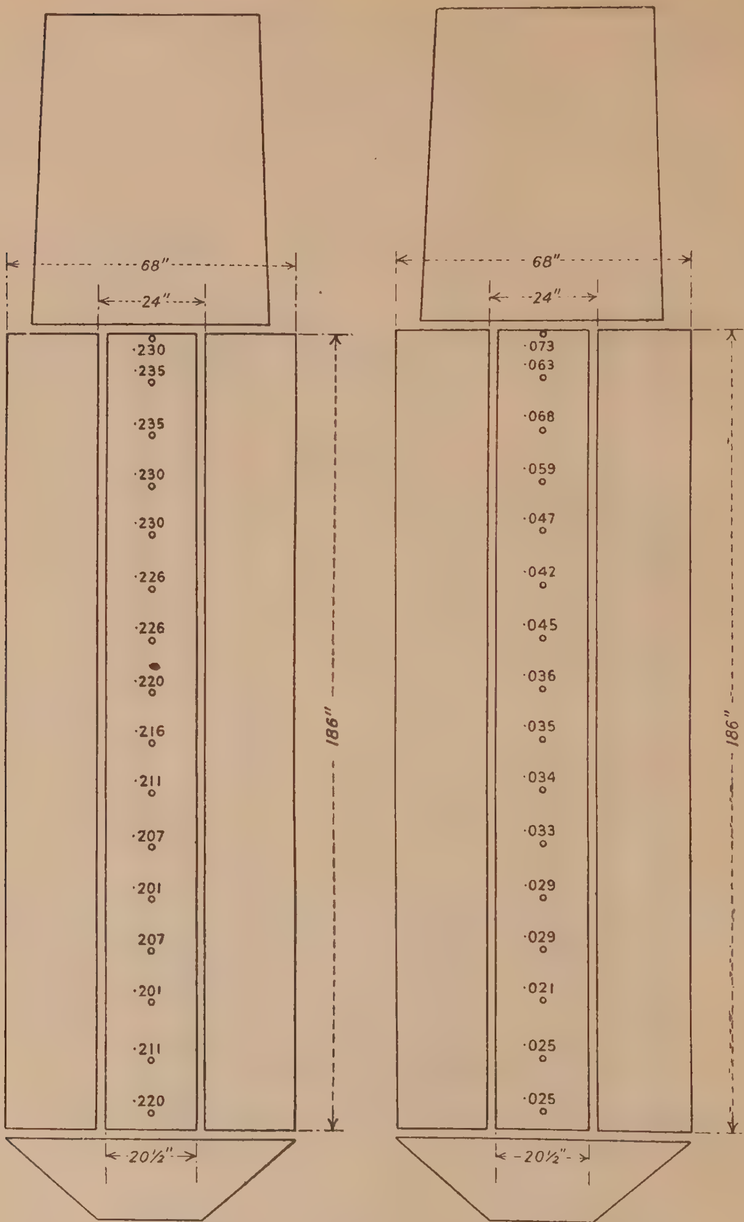
Example 14 e.—64-ton Ingot. Distribution of Phosphorus.



CARBON
Cast Analysis, 0·27.
a.

MANGANESE
Cast Analysis, 0·715.
b.

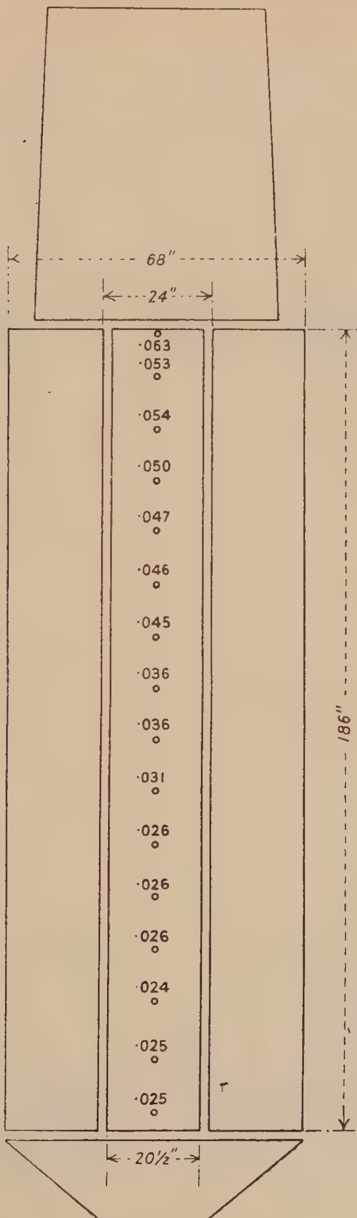
EXAMPLE 15.—110-ton Ingot. Distribution of Elements.



SILICON
Cast Analysis, 0·244.
c.

SULPHUR
Cast Analysis, 0·033.
d.

EXAMPLE 15.—110-ton Ingot. Distribution of Elements.

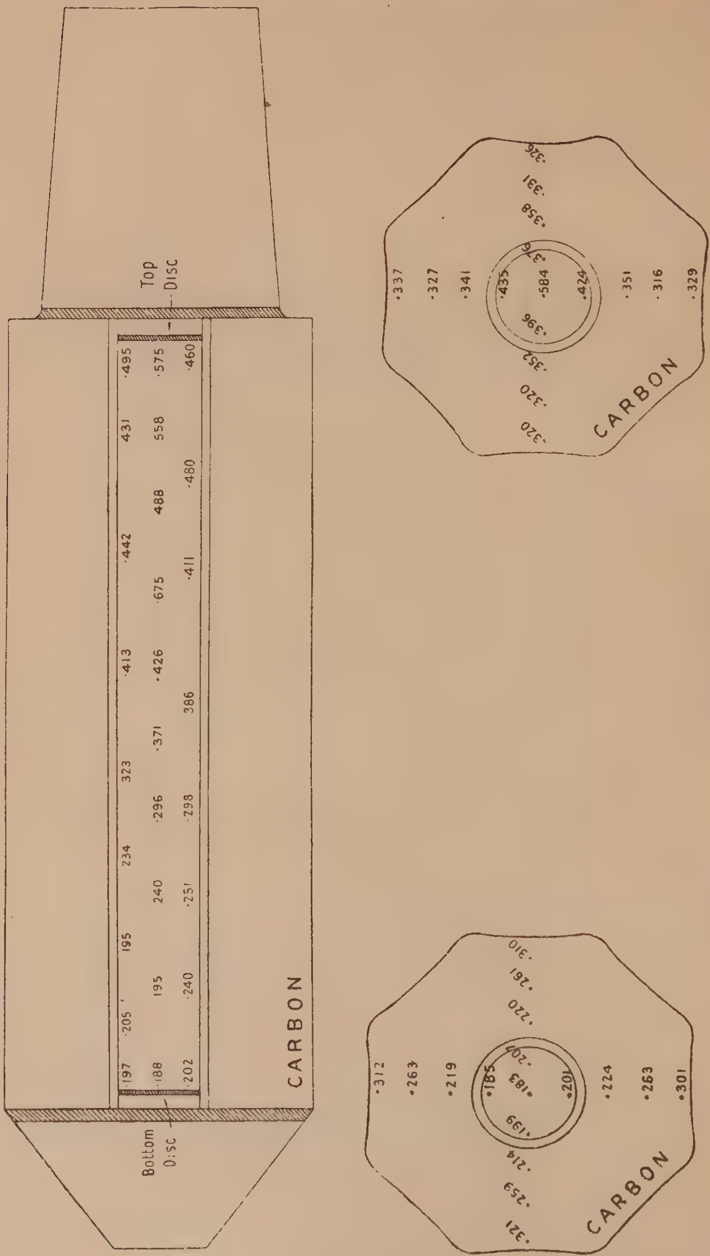


PHOSPHORUS

Cast Analysis, 0·024.

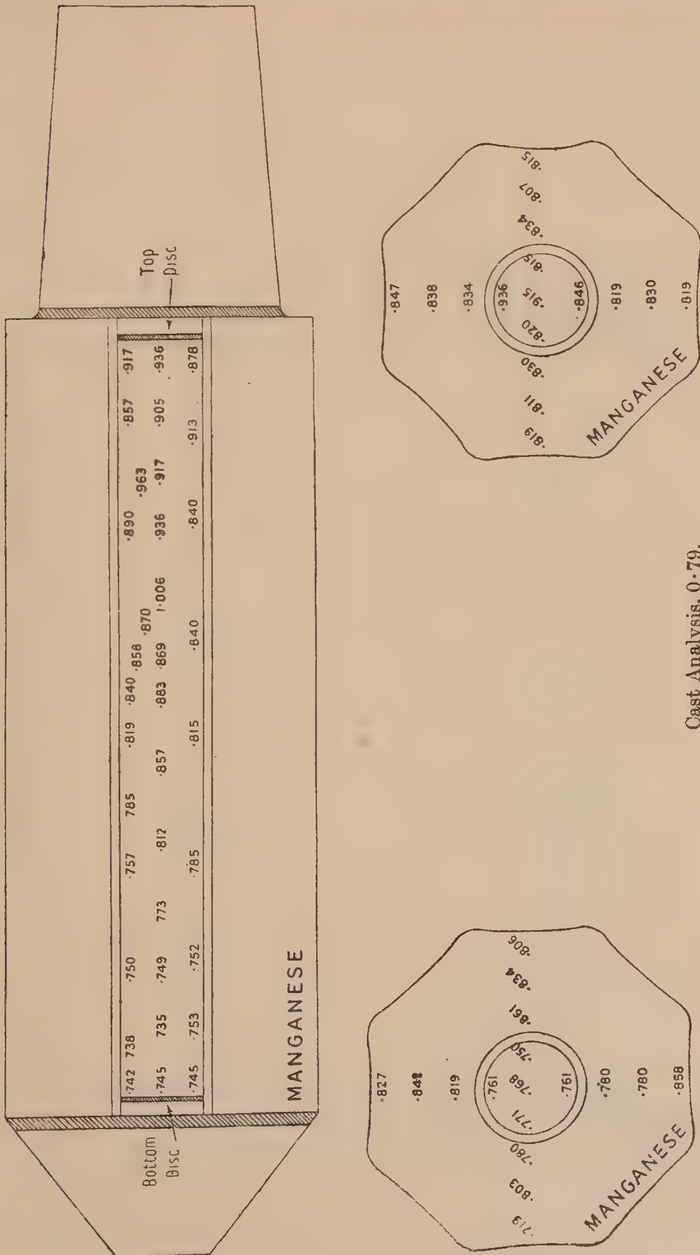
e.

EXAMPLE 15.—110-ton Ingot. Distribution of Phosphorus.



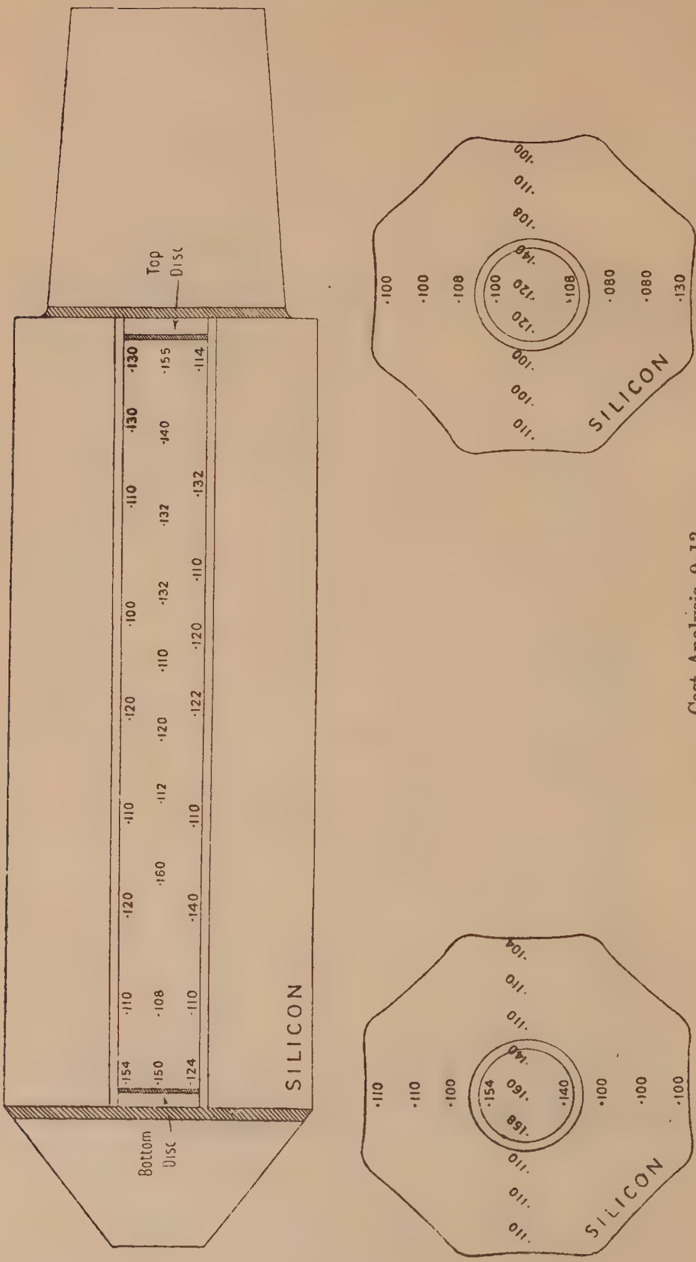
Cast Analysis, 0·32.

EXAMPLE 16*a*.—172-ton Ingot. Distribution of Carbon.



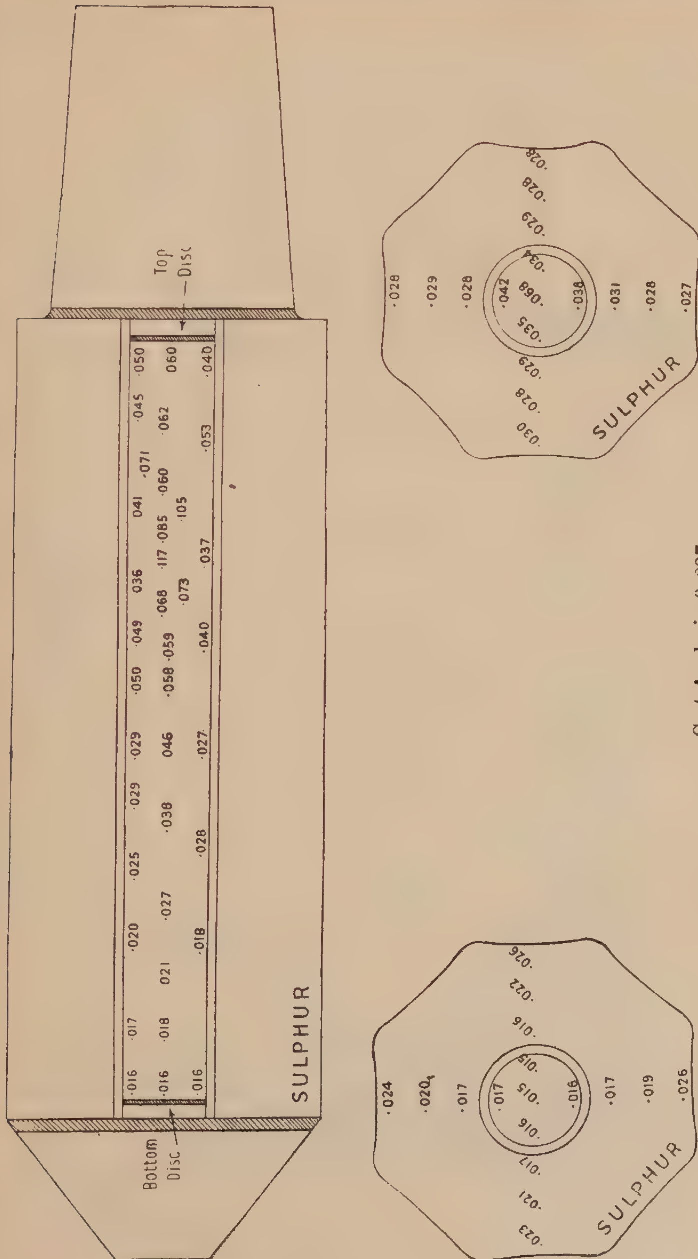
Cast Analysis, 0·79.

EXAMPLE 16*b*.—172-ton Ingot. Distribution of Manganese.



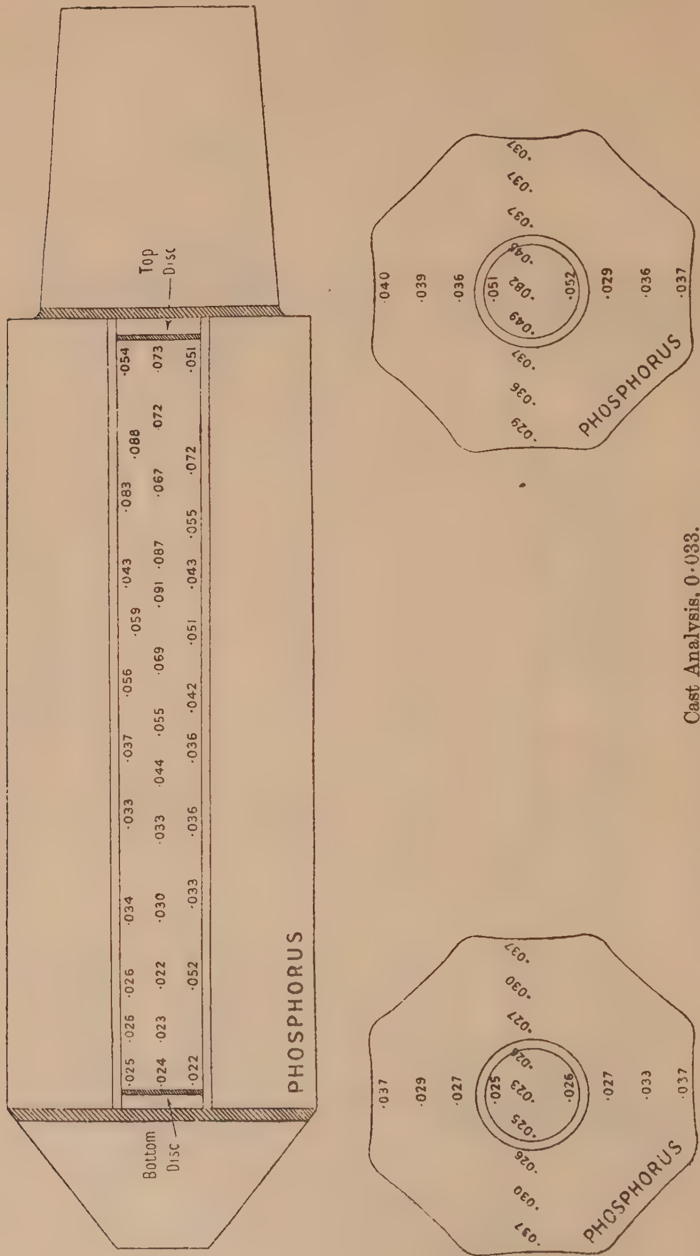
Cast Analysis, 0·13.

EXAMPLE 16c.—172-ton Ingot. Distribution of Silicon.



Cast Analysis, 0·027.

EXAMPLE 16*d*.—172-ton Ingot. Distribution of Sulphur.



Cast Analysis, 0·033.

EXAMPLE 16 e.—172-ton Ingot. Distribution of Phosphorus.

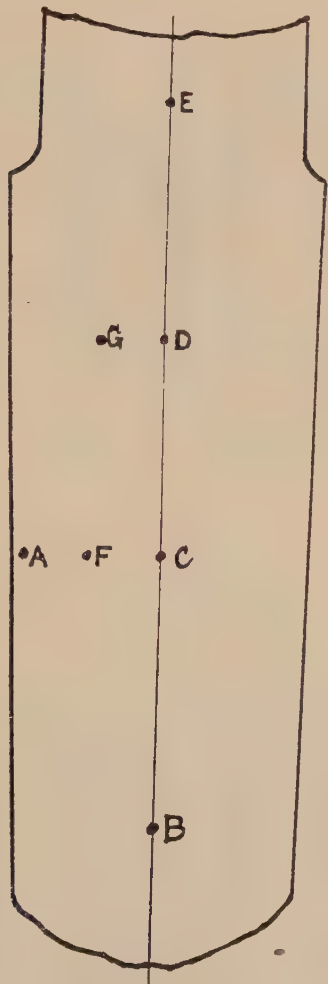


FIG. 5.—A diagrammatic indication of the positions in the ingots selected for a comparison of the distribution of the elements.

TABLE II.—*Carbon.*

Example.	Position.							
	A.	*B.*	*C.*	*D.*	*E.*	*F.*	*G.*	*X.*[1]
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	...	...	...	...	...	...	...	...
2	0·52	0·48	0·49	0·53	0·79	0·52	0·54	0·52
3	0·44	0·41	0·42	0·46	0·93	0·45	0·46	0·41
4	0·38	0·34	0·33	0·35	0·41	0·40	0·39	0·34
5	0·37	0·31	0·29	0·35	0·45 +	0·33	0·40	0·34
6	0·60	0·53	0·59	0·64	0·66 +	0·64	0·64	0·60
7	0·37	0·35	0·35	0·42	0·62	0·39	0·39	0·40
8	0·40	0·31	0·39	0·45	0·42 +	0·43	0·43	0·39
9	0·21	0·18	0·22	0·23	0·27	0·23	0·27	0·21
10	0·30	0·21	0·28	0·30	0·42 +	0·29	0·30	0·30
11	0·21	0·16	0·19	0·23	0·25 +	0·21	0·25	0·21
12	0·43	0·35	0·38	0·49	0·70	0·47	0·48	0·44
13 (*a*)	0·36	0·28	...	0·42	...	...	...	...
(*b*)	0·34	0·24	...	0·39	...	...	...	...
14	0·41	0·33	0·40	0·45	0·51 +	...	...	0·40
15	...	...	...	...	...	...	...	...
16	0·33	0·19	0·35	0·50	0·60 +	...	...	0·32

TABLE III.—*Manganese.*

Example.	Position.							
	A.	*B.*	*C.*	*D.*	*E.*	*F.*	*G.*	*X.*[1]
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	...	...	...	...	...	...	...	...
2	0·84	0·80	0·84	0·82	0·74	0·84	0·84	0·84
3	1·03	0·99	1·00	1·00	0·98	1·03	1·04	1·06
4	0·75	0·74	0·73	0·75	0·77	0·74	0·76	0·72
5	0·74	0·69	0·70	0·73	0·74	0·72	0·74	0·70
6	0·77	0·81	0·76	0·79	0·80	0·77	0·78	0·77
7	0·83	0·78	0·81	0·85	0·97	0·87	0·83	0·84
8	0·92	0·95	1·01	1·04	1·06	1·01	1·03	0·96
9	...	...	...	...	...	...	...	0·51
10	0·74	0·68	0·70	0·74	0·80 +	0·75	0·77	0·74
11	0·67	0·64	0·64	0·67	0·68 +	0·67	0·68	0·67
12	0·78	0·73	0·74	0·78	0·93	0·78	0·80	0·78
13	...	...	...	...	...	...	...	...
14	0·63	0·63	0·63	0·68	0·69 +	0·64	0·69	0·63
15	...	...	...	...	...	...	...	...
16	0·79	0·73	0·86	0·92	0·93 +	...	...	0·79

[1] X is the assumed mean composition of the cast as determined by pit sample or other means.

TABLE IV.—*Silicon.*

Example.	Position.							
	A.	*B.*	*C.*	*D.*	*E.*	*F.*	*G.*	*X.*[1]
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	...	...	...	...	...	...	...	...
2	0·21	0·20	0·21	0·21	0·22	0·21	0·22	0·21
3	0·52	0·51	0·50	0·52	0·54	0·53	0·52	0·52
4	0·23	0·23	0·23	0·22	0·22	0·23	0·22	0·18
5	0·15	0·14	0·15	0·15	0·17	0·14	0·14	0·16
6	0·21	0·20	0·21	0·21	0·23	0·23	0·21	0·23
7	...	...	...	...	...	...	...	0·12
8	...	...	...	...	...	...	...	0·08
9	...	...	...	...	...	...	...	...
10	0·13	0·17	0·13	0·14	0·15	0·15	0·14	0·14
11	0·18	0·20	0·19	0·19	0·19 +	0·19	0·19	0·17
12	0·27	0·27	0·27	0·28	0·29	0·28	0·29	0·29
13	...	...	...	...	...	...	...	...
14	0·16	0·16	0·17	0·17	0·20 +	0·16	0·16	0·16
15	...	...	...	...	...	...	...	...
16	0·13	0·11	0·11	0·14	0·15 +	...	...	0·13

TABLE V.—*Sulphur.*

Example.	Position.							
	A.	*B.*	*C.*	*D.*	*E.*	*F.*	*G.*	*X.*[1]
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	...	...	...	...	...	...	...	0·041
2	0·037	0·034	0·032	0·036	0·052	0·04	0·039	0·037
3	0·052	0·047	0·046	0·055	0·068	0·055	0·056	0·056
4	0·040	0·033	0·034	0·039	0·045	0·041	0·043	0·04
5	0·048	0·037	0·034	0·048	0·058	0·041	0·053	0·049
6	0·038	0·031	0·036	0·039	0·041	0·038	0·043	0·038
7	0·035	0·027	0·031	0·05	0·064	0·037	0·046	0·034
8	0·021	0·016	0·018	0·029	0·031 +	0·022	0·022	0·024
9	0·018	0·017	0·022	0·03	0·03 +	0·025	0·033	0·027
10	0·019	0·009	0·017	0·026	0·042	0·017	0·023	0·017
11	0·031	0·024	0·026	0·031	0·035 +	0·036	0·035	0·032
12	0·030	0·025	0·036	0·038	0·067	0·034	0·037	0·033
13	...	...	...	...	...	...	...	...
14	0·035	0·029	0·034	0·048	0·053 +	0·04	0·05	0·035
15	...	...	...	...	...	...	...	...
16	0·027	0·018	0·05	0·08	0·06 +	...	...	0 027

[1] *X* is the assumed mean composition of the cast as determined by pit sample or other means.

TABLE VI.—*Phosphorus.*

Example.	Position.							
	A.	*B.*	*C.*	*D.*	*E.*	*F.*	*G.*	*X.*[1]
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	...	...	...	...	...	...	...	...
2	0·036	0·032	0·033	0·035	0·046 +	0·037	0·039	0·036
3	0·056	0·047	0·050	0·055	0·068	0·057	0·062	0·052
4	0·044	0·040	0·039	0·045	0·05	0·04	0·052	0·043
5	0·046	0·037	0·033	0·046	0·055	0·042	0·051	0·039
6	0·046	0·037	0·040	0·044	0·049	0·040	0·048	0·040
7	0·042	0·032	0·036	0·052	0·072	0·042	0·04	0·042
8	0·023	0·023	0·026	0·031	0·031 +	0·025	0·026	0·025
9	0·057	0·050	0·056	0·059	0·083 +	0·058	0·067	0·059
10	0·010	0·009	0·011	0·011	0·015	0·011	0·011	0·010
11	0·042	0·037	0·040	0·050	0·051 +	0·05	0·051	0·040
12	0·036	0·030	0·030	0·041	0·063	0·037	0·037	0·042
13	...	...	...	...	...	...	...	...
14	0·038	0·026	0·04	0·05	0·051 +	0·04	0·05	0·038
15	...	...	...	...	...	...	...	...
16	0·033	0·023	0·06	0·09	0·073 +	...	...	0·033

[1] *X* is the assumed mean composition of the cast as determined by pit sample or other means.

silicon, sulphur, and phosphorus, of the several ingots where the completeness of the analyses makes it possible to state a figure for the critical positions selected and indicated in Fig. 5 (p. 91).

In comparing the figures obtained in this way it is of interest not only to note the variations in the percentage of a given element within an ingot and in different ingots, but also to endeavour to observe how the segregation of one element compares with that of others.

Reference may be made at this stage to the various ways in which the segregating elements may exist in the hot solid steel. For instance, the manganese may be present in three combinations :

(*a*) To a small extent as a double carbide of iron and manganese.
(*b*) In combination with sulphur as manganese sulphide.
(*c*) As the oxide of manganese, more or less associated with silica as manganous silicates.

The silicon may be present either in solid solution as silicide of iron, or as oxide when it exists as a constituent of the silicate inclusions. The phosphorus may be considered to exist as phosphides in solid solution, and the sulphur to exist as non-metallic

inclusions of sulphide of manganese, or as a double sulphide of manganese and iron. The carbon is agreed to be in solid solution either as carbide or carbon, while the sulphides and silicates most probably exist in the molten steel as distinct entities. The progressively diminishing volume of liquid steel naturally becomes of higher concentration in these compounds owing to the separation of crystals less rich in the solutes.

It is therefore clear that, broadly speaking, segregation of all the compounds originally associated in or with the liquid steel may be expected to occur, but that the study of the varying concentration of one element as compared with another will not indicate a quantitative relationship.

In Table VII. an attempt has been made to arrange the data, obtained by chemical analysis from the various representative ingots, in a statistical manner, with a view to determining the relative composition at the positions more or less arbitrarily defined in Fig. 5. For this purpose the data of the nine ingots, 2 to 6, 10, 11, 12, and 14, have been taken, as these cases are sufficiently complete.

TABLE VII.—*Average Composition of the Representative Ingots as shown by Analysis of Drilled Samples at the Selected Positions shown in Fig.* 5 (p. 91).

The figures for the various elements are expressed as a percentage of the amount of all the elements as ascertained by analysis of the corresponding test ingot.

The ingots included in this table are Nos. 2 to 6, 10, 11, 12, and 14, the data for these ingots being sufficiently complete for the purpose.

Position in the Ingot as Defined in Fig. 5.	Average Figures for all the Nine Ingots.					
	C.	Mn.	Si.	S.	P.	All Elements.
E	141·8	103·9	107·7	148·8	134·8	127·4
G	112·1	103·4	101·8	115·1	118·4	110·2
D	106·8	100·9	101·8	114·2	108·7	106·5
F	104·6	100·7	104·2	101·3	106·0	103·4
A	103·8	100·6	100·7	99·0	104·0	101·6
Amount of the element contained in the test ingot	100	100	100	100	100	100
C	94·7	97·7	101·3	88·0	93·8	95·1
B	85·7	97·2	103·0	76·6	86·7	89·8

An examination of the figures in the table will show that in general the order of the several chosen positions as regards increasing concentration of the five elements is *B*, *C*, *A*, *F*, *D*, *G*, and *E*—*B* usually contains the smallest amount of each element, and *E* in every case the largest. In individual cases this order varies somewhat, but not greatly. Upwards along the axis line the concentration increases from *B* progressively through *C* and *D* to *E* at the top of the ingot, where the greatest concentration of the elements is found. *A* approaches reasonably close to the composition of the test ingot in all cases. The intermediate position *F* is of slightly higher concentration than *A* or *C* taken at about the same horizontal level on the outside and axis of the ingot respectively. In a similar way *G* contains usually a higher percentage of the several elements than *D* at about the same level on the axial line.

Silicon is an exception, showing a rather different order of concentration. Too much stress, however, should not be laid on these particular figures, as the amount of the element is in general small. Due probably to their ready diffusion, silicon and manganese are, in fact, shown to be not markedly segregating elements, although a portion of the manganese must segregate as MnS. The greatest heterogeneity is shown by sulphur. Carbon and phosphorus give figures more or less parallel to each other, but with a rather less range of variation than that of sulphur.

It should be noted that the figures are derived from analyses made on drilled samples, and that, therefore, they cannot be expected to exhibit the actual extremes of concentration of the various elements, since segregated and non-segregated areas may easily be covered by the drill. The results nevertheless exhibit quite clearly the features discussed at greater length in Section IV. of this Report.

In Table VIII. the analytical data for the various representative ingots have been tabulated in such a way as to show the range of composition in respect of the various elements again as indicated by chemical analysis of drilled samples from each.

For this purpose, omitting the discarded upper portion of the ingot, the highest percentage of each element, and the lowest, have been taken from Tables II., III., IV., V., and VI.—that is, these analyses have been selected as representing the range of

TABLE VIII.—*Range of Composition in each of the Representative Ingots, as obtained by Analysis of Drilled Samples at the Positions Indicated in Fig.* 5 (p. 91).

In preparing this table the data for position E, which is in the discarded portion of the ingot, have been excluded.

The figure of "range per cent." for each ingot and element is expressed as a percentage of the amount of the element as ascertained by analysis of the corresponding test ingot. The ingots are arranged in order of increasing weight.

Ingot No.	Weight of Ingot.		Carbon.				Manganese.				Silicon.				Sulphur.				Phosphorus.			
	Tons	Cwts	Test Ingot.	Max.	Min.	Range. Per Cent.	Test Ingot.	Max.	Min.	Range. Per Cent.	Test Ingot.	Max.	Min.	Range. Per Cent.	Test Ingot.	Max.	Min.	Range. Per Cent.	Test Ingot.	Max.	Min.	Range. Per Cent.
2	1	5	0·52	0·54	0·48	12	0·84	0·84	0·79	6	0·21	0·22	0·20	10	0·037	0·040	0·032	22	0·036	0·038	0·032	17
3	2	10	0·41	0·46	0·40	15	1·06	1·04	0·98	6	0·52	0·52	0·50	4	0·056	0·057	0·044	23	0·052	0·062	0·047	29
4	2	15	0·34	0·40	0·33	21	0·72	0·78	0·73	7	0·18	0·23	0·22	6	0·040	0·043	0·032	18	0·043	0·052	0·039	30
6	2	18	0·60	0·64	0·53	18	0·77	0·79	0·76	4	0·23	0·21	0·20	2	0·038	0·040	0·031	24	0·040	0·048	0·037	28
5	2	18½	0·34	0·40	0·31	28	0·70	0·74	0·69	7	0·16	0·15	0·14	4	0·049	0·050	0·034	33	0·039	0·051	0·034	44
7	3	5	0·40	0·45	0·35	25	0·84	0·85	0·78	8	...	...	...	...	0·034	0·050	0·027	68	0·042	0·048	0·032	38
8	8	0	0·39	0·45	0·31	35	0·96	1·04	0·95	9	...	...	...	...	0·024	0·029	0·016	54	0·025	0·031	0·023	32
9	8	5	0·21	0·28	0·18	48	0·51	...	...	...	...	...	...	...	0·027	0·033	0·017	59	0·059	0·069	0·050	32
10	10	10	0·30	0·34	0·21	43	0·74	0·77	0·68	12	0·14	0·14	0·13	7	0·017	0·026	0·009	100	0·010	0·011	0·009	20
11	20	0	0·21	0·25	0·16	42	0·67	0·68	0·64	6	0·17	0·20	0·19	5	0·032	0·035	0·024	34	0·040	0·051	0·037	35
12	24	17½	0·44	0·49	0·35	32	0·78	0·80	0·73	9	0·29	0·29	0·27	7	0·033	0·048	0·025	70	0·042	0·042	0·030	29
13 (*a*)	54	0	0·36[1]	0·42	0·28	39	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
13 (*b*)	54	0	0·34[1]	0·39	0·24	44	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
14	64	0	0·40	0·50	0·33	43	0·63	0·69	0·63	10	0·16	0·17	0·16	6	0·035	0·050	0·029	60	0·038	0·050	0·026	63
15	110	0	...	0·37	0·15	...	...	0·71	0·63	...	...	0·23	0·20	...	...	0·059	0·021	...	...	0·050	0·024	...
16	172	0	0·33[1]	0·55	0·19	109	0·79	0·92	0·73	11	0·13	0·14	0·11	23	0·030	0·080	0·018	206	0·033	0·090	0·023	203

[1] In these cases, in the absence of the test ingot analysis, the analysis at position A is taken for this column.

composition found in the ingot proper. They, therefore, also represent approximately the range of composition likely to be met with in each case in the chemical examination of such ingots for practical purposes.

In the practical examination of ingots it is by means of analyses obtained from drilled samples that the heterogeneity of the ingots is usually judged ; but as previously stated the analysis of a drilled sample gives only the average composition of the sample, and therefore this method of examination does not indicate the highest concentrations of the segregating elements. The figures given in Table VIII. may therefore be taken as bearing more particularly on this aspect of the matter. The table not only establishes that some segregation, especially of carbon, sulphur, and phosphorus, takes place in ingots of all the various sizes and types considered, but also clearly shows that the degree of heterogeneity is more pronounced in the larger ingots ; that there should be an entirely regular progression in the figures for range per cent. is, of course, hardly to be expected, having in mind the varying forms of the ingots and the different average amounts of the various elements which they contain, these amounts only being utilised in an empirical manner by dealing with the figures on a percentage basis.

Here again it is apparent that manganese and silicon are not segregated to any very marked extent.

Section IV.—*A General Discussion on the Heterogeneity found in Steel Ingots.*

The preceding Sections I., II., and III., dealing with observed facts, have the unanimous concurrence of all members of the Committee. This Section IV., dealing as it does with the theoretical aspects of the problems involved, is a collective attempt to present various ideas worthy of consideration when an explanation of heterogeneity is being sought ; the ideas put forward have not necessarily the unanimous support of all the members of the Committee.

In attempting to explain the heterogeneity existing in all cast masses of steel, the investigator experiences extreme difficulty in distinguishing between the various influences at work and in

determining their comparative effect. The members of the Committee have individually and collectively endeavoured to form a picture of the mechanism of freezing with a view to accounting for the lack of homogeneity found in the various ingots. Complete agreement on all the aspects of the matter was hardly to be expected and was not attained. The following observations, however, will be of interest, as indicating the trend of the ideas put forward, and will, it is hoped, be of value to others who may seek to carry the matter further.

A consideration of the subject is rendered most difficult by the paucity of available physical data concerning the properties of iron in combination with the other elements present in the liquid state and at temperatures near the freezing point. Thus, with few exceptions, the equilibrium diagrams are not yet definitely established. Further, it is not yet known whether, or to what degree, there is a modification in the density of the steel when it freezes. The experimental difficulties in the way of such determinations are considerable, but it is hoped that investigators will, in the near future, be able to deal with this and allied problems.

(*a*) Steel is not a simple metal; in its liquid form it is a solution of the other elements or their compounds present in the iron. When solidification begins the crystals which constitute the primarily formed solid steel are solid solutions of these same elements or their compounds in iron, but, owing to selective freezing, according to well-known laws, they are of a greater purity than the original liquid. The remaining liquid steel must therefore become progressively richer in these compounds, and probably of lower density than the original steel.

The data presented in Section III. indicate that all ingots, no matter what their size, relative proportions, method of casting, or processes of manufacture, show segregation of certain elements in well-defined zones. Further, that the degree of segregation is highest for the elements carbon, phosphorus, and sulphur, but is almost negligible for manganese and silicon. A study of the equilibrium diagrams of the various elements concerned, first with iron alone and then in ternary mixtures, throws much light upon the subject. It is now established that, in the ranges of composition found in steel, the elements carbon, silicon,

manganese, and phosphorus are completely soluble in liquid iron, and more or less soluble in solid γ-iron—*i.e.* the diagrams are analogous to types I. or II., Figs. 6 and 7. With carbon and phosphorus, which have a limited solubility in the solid γ-iron, the diagram is of the type shown in Fig. 6, while the diagrams of manganese and silicon, which are completely soluble in the solid state, belong to the type shown in Fig. 7.

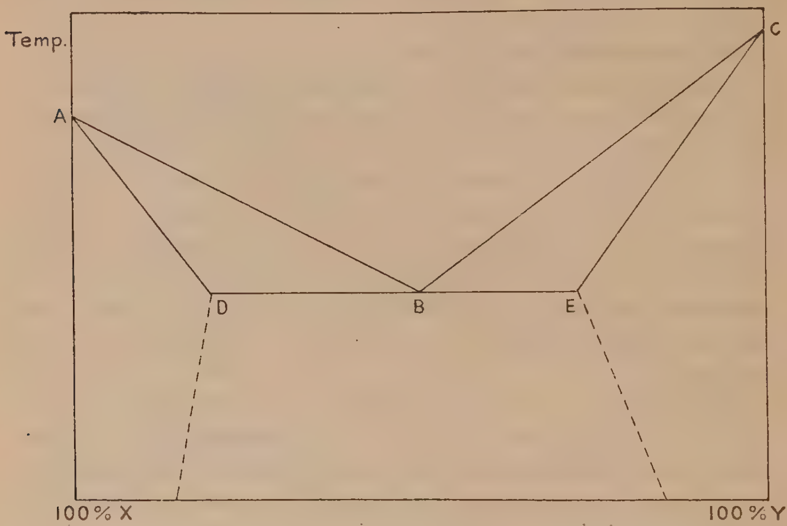


FIG. 6.—A Binary System in which there is Limited Solubility.

Consider the process of solidification of a typical binary system of such types (Fig. 8): an alloy of metal A containing X per cent. of B will exhibit no well-defined freezing point, but rather a range of temperature during which freezing will occur. Such an alloy at $t_0°$ C. would be completely fluid and homogeneous; freezing would commence at, or slightly below, the temperature $t_1°$, and the first crystals formed will contain, not X per cent. of element B, but p_1 per cent.—*i.e.* the first formed crystals will contain less of B and the remaining liquid slightly more of B than the original liquid alloy.

As the liquid cools to temperature $t_3°$ the crystals formed when equilibrium is established will have the composition p_3 per cent.

of B, while the remaining liquid will contain q_3 per cent. of B. Similarly at $t_4°$, the crystals will contain p_4 per cent. of B, while the liquid will now contain q_4 per cent. of B; on approaching the completion of freezing at $t_2°$ the remaining liquid, and therefore the last formed crystals, would approach q_2 per cent. of B—*i.e.* the remaining liquid becomes more and more rich in B as the process of freezing proceeds.

From this diagram (Fig. 8) it will be clear that the difference in composition between the growing crystals and the still liquid

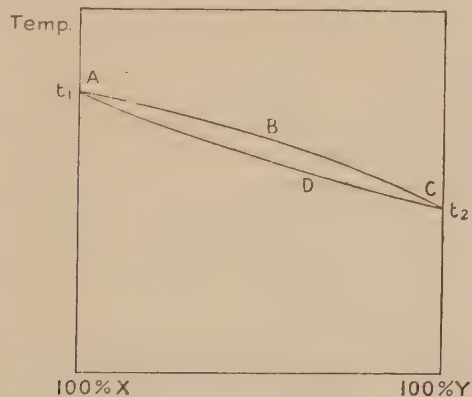


Fig. 7.—A Binary System in which there is Complete Solubility in the Solid State.

alloy will depend upon the horizontal distance pq—the difference in concentration of the liquidus and solidus at the various temperatures. If the liquidus and solidus are close together the variation of composition will be smaller than when the two curves are farther apart. In the binary systems, Fe–Mn, Fe–Si, where the elements are mutually soluble in all proportions in the range of composition under review, the distance between the liquidus and solidus is very small. Hence the variation in composition of the crystals or liquid is very small—the segregation is negligible. With the systems Fe–C, Fe–P, the separation of the liquidus and solidus is relatively large, and correspondingly large variations of composition are found, *i.e.* the segregation is much more marked.

A further point is to be noted. In the diagrams Fe–C, Fe–P, it will be seen that as the percentage of carbon or phosphorus

increases, the divergence of the liquidus and solidus becomes more and more pronounced, *i.e.* the greater is the difference in composition between the growing crystals and the mother liquor, and therefore the greater is the tendency to heterogeneity. The degree of segregation increases as the carbon and phosphorus contents increase. On the other hand, with Fe–Mn and Fe–Si the two curves run approximately parallel and there is little or no

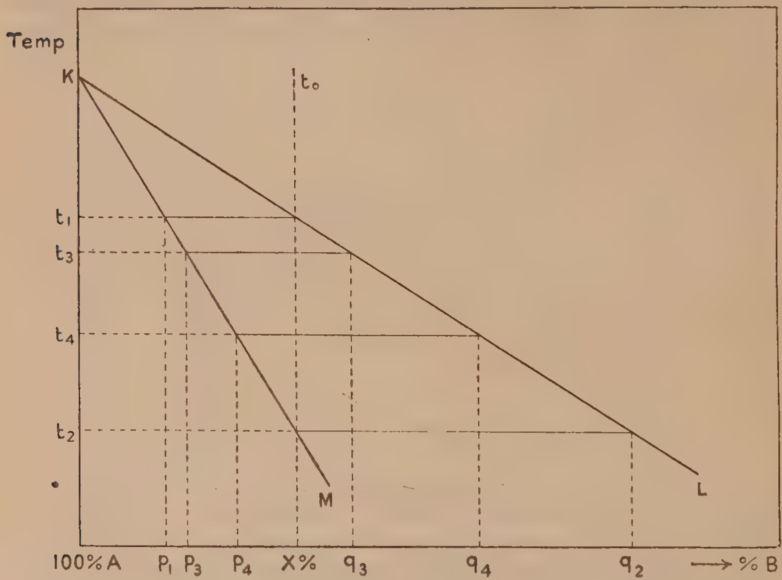


FIG. 8.—Liquidus and Solidus of a Binary System.

increased divergence as the amount of alloying element increases. Hence in these cases there is no tendency for an increase in the degree of segregation.

If the ternary systems are considered, it is found that more marked differences are to be observed. With manganese or silicon alloying with iron and carbon, the added element forms solid solutions with the γ-iron or cementite, and there is no tendency to increase the heterogeneity of the crystals. On the other hand, if phosphorus is the third element with iron and carbon, the Fe_3P has but a very slight solubility in γ-iron and is insoluble in Fe_3C. As a result there is a tendency to form a

ternary eutectic—well seen in phosphoric cast irons—and there is a notable depression of the solidus, *i.e.* the gap between liquidus and solidus is increased and the tendency to segregation is more marked.

Another very important factor in this process of differential or selective freezing is the *rate of cooling* through the freezing range. It is considered by some that, as the speed of cooling becomes less, the tendency to heterogeneity will diminish because more time is available for the diffusion of the constituents into the purer crystals first formed. It is, however, to be deduced from existing diagrams that the differences of composition p_3 and q_3 for the crystals and liquid respectively, at temperature $t_3°$, represent the compositions only when equilibrium is established, and for this very slow cooling is essential. If the cooling is rapid there is not the requisite time for the complete separation of the two phases, and the less marked is the heterogeneity of the crystals; the slower the cooling through the freezing range the more marked are the differences in composition.

This effect is of particular importance. First, in all ingots the outer layers pass through the freezing range very rapidly on account of the great absorption of heat by the mould, and there is not sufficient time for the phases to separate; hence the crystals of steel formed show little or no variation in composition: there is little segregation. As the rate of cooling falls, the time occupied in passing through the freezing range increases and the variations in composition become more marked; it is suggested that in the central zone, where presumably the rate of cooling is slowest, the separation of the phases is the most complete and the crystals show the lowest percentages of the segregating elements carbon and phosphorus.

Secondly, the cross-sectional area of the ingot has a fundamental bearing upon the process: the greater the diameter of the ingot the slower must be the rate of cooling of the interior portions, and therefore the more marked will be the differences of composition observable.

From such considerations it appears that even steel made under the most perfect conditions, perfectly free from extraneous material and of uniform composition when entering the mould, must exhibit, when solid, certain variations of composition because

of this selective freezing. The degree to which these variations manifest themselves will increase :

(1) As the carbon and phosphorus content of the steel increases ;
(2) As the rate of freezing of the ingot falls ; and
(3) As the cross-section of the ingot increases in dimensions.

The factors governing the segregation of sulphur require separate consideration. So far as can be ascertained from the studies already made on the question, it is very difficult to assign any definite composition to the sulphide which is present in liquid or solid steel.

When manganese is added to the steel in the bath, the distribution of the sulphur between the two elements iron and manganese is determined by the relative amounts of the two metals present and their respective affinities, and the sulphide is always of a complex character (FeMn)S. It is generally accepted that this complex is insoluble in liquid iron, and its distribution is governed by a different law from that of the other constituents. In addition, there is no doubt that this sulphide is of lower density than liquid iron. It has been suggested that there are reactions between these sulphides and the oxides left in the metal, as they are sometimes found to be associated together in the segregated areas.

Sulphur, then, mainly exists in the liquid steel in the form of minute globules of an immiscible, complex sulphide. During the rapid formation of the columnar crystals in an ingot, these globules are pushed farther into the interior of the ingot by the growing crystallites, and as a result there is an increase of the sulphur content in the layer of mother liquor at the face of crystallisation. The small globules coalesce and comparatively large masses collect at the tips of the columnar crystals. These, by virtue of their lower density, commence to rise, but are entangled by the growing crystals, and hence give rise to the first zone of segregate, which is found as string-like masses at the surface of the columnar crystals.

In the mass of the still liquid steel of the ingot a similar process occurs. The small globules of sulphide coalesce and tend to rise, the larger the globule the quicker being the rate of rising. The

globules from the central or axial parts of the ingot rise into the upper portion and ultimately into the head, leaving the lower, central zone much lower in sulphur than any other zone. In the intermediate zones, between the columnar crystals and the axial zone, the sulphur segregate will not be able to rise as far as the head before it is trapped by the continuously advancing wall of the ingot as freezing proceeds. The particles in the outer zones will have but a small period of time to rise, and therefore only travel a short distance before the thickening wall intercepts their further progress. The nearer the particles are situated to the axis of the ingot, the longer periods will they have for rising, and therefore the farther will they proceed in their journey towards the head before being arrested by the solidifying steel shell of the ingot.

If this picture be correct, then it would be anticipated that the lines of segregate or ghost lines would show a gradual taper inwards as they pass from the bottom corners of the ingot towards the head, and that the degree of segregation would become more pronounced as the head is approached. Such is experimentally found to be the case, and is strikingly demonstrated in Fig. 1 (Plate II.).

A further point of interest arises from these considerations. A study of the segregated areas, and in particular of the segregate isolated from Examples 9 and 12, shows that although the segregation of carbon, manganese, silicon, and phosphorus proceeds by a physical law different from that governing the segregation of sulphur, yet the elements carbon, sulphur, and phosphorus are invariably found to segregate together. It has been suggested that the globules of sulphide may act as nuclei for the coalescence of the minute particles of the impure mother liquor resulting from the selective freezing outlined above. The globules at the surface of crystallisation would therefore become rich in carbon and phosphorus, and would act as carriers of these elements from the body of the ingot into the head.

(*b*) As already stated, after teeming the cooling of the steel at first takes place chiefly by absorption of heat by the mould walls. Subsequently, cooling proceeds by transmission of heat through the mould, which heat is radiated from the outer surface. These two cooling actions occur simultaneously, but the first starts from

a maximum value and decreases with time, and the second starts from zero value and increases with time up to a certain point, when it slowly decreases again. The first action is capable of freezing, at any particular section of the mould, a considerable mass of steel. Subsequent cooling by conduction through the mould may be, under some conditions, slightly more rapid at the top, owing to its thinner section, than at the bottom, and therefore the isothermal lines otherwise parallel to the surface may tend to become modified. Broadly, however, the freezing of an ingot can be considered to occur in three successive periods:

(1) Almost instantaneous freezing.
(2) Very rapid freezing.
(3) Comparatively slow freezing.

The duration of these periods depends, as previously indicated, upon the rate at which the heat escapes from the solidifying steel.

The effect on the nature of the crystallisation of the rate at which heat is removed by the surrounding mould will obviously depend upon the conductivity of the steel, since up to a certain point, depending also upon the thickness of the wall of the mould, the more rapid the transference of heat from the interior, the greater will be the chilling effect. The heat conductivity of steels of different compositions undoubtedly varies, and therefore a better knowledge of the conductivity of steels both in the liquid and also the solid state, and of steels of different compositions, at all pertinent temperatures is essential. In these circumstances, and in view of the difficulties of its experimental determination, the steepness of the temperature gradient between the exterior of an ingot and its axis must therefore for the present be largely a matter of surmise. But in any case the extent of the columnar crystallisation, under given conditions, would appear to be influenced by the conductivity.

The possibility and extent of convection currents within the still fluid portion of the ingot, as freezing continues, is also connected with the conductivity. At any time after the mould is filled the hottest zone will be in the neighbourhood of the centre of the axis, since heat is passing out at the top, sides, and bottom.

Consequently, the top half of the ingot will tend to have convection currents, especially if the temperature gradient is large, while in the lower half there will not be the same tendency, since here the coldest and most dense metal is at the bottom. Such convection currents, if they occur, will have an important influence on segregation.

Again, the rates of diffusion of the various impurities in the solid and molten steel, which must also be taken into account, are unknown. The position, too, of the liquidus and solidus of the quaternary system Fe–C–P–Mn, which has an important bearing, has not yet been determined, even for the small area covering steel compositions. No idea can be formed, therefore, of the degree of segregation to be expected in different steels and under widely varying cooling conditions, except from investigations similar to those under discussion. The reason why manganese and silicon segregate very slightly, if at all, may be due, as previously suggested, to a very rapid diffusion of these elements.

Whilst dealing with these matters it is well to put on record the possibility of another influence in producing heterogeneity. It may be shown that, as a result of the known laws governing osmotic pressure, temperature gradients in a solution will influence the distribution of the solute. In a dilute solution the osmotic pressure is proportional to concentration and to absolute temperature. Hence a solution in which equilibrium has been attained in the distribution of the dissolved atoms or molecules throughout the mass will always be less concentrated in the hotter portions in order that the osmotic pressures shall be balanced. This deduction is substantiated by actual experiment with ordinary aqueous solutions. Time for perfect equilibrium can only be given if the temperature differences are maintained by external application of heating and cooling devices. The rate of diffusion, *i.e.* the rate of segregation, will depend upon temperature gradients as well as upon the actual temperature differences. As to whether liquid iron solutions such as those under discussion can be considered to behave in an analogous manner can only at present be considered as within the realm of conjecture.

It has been suggested that the very thin outer layer is a "chill" layer formed by the almost instantaneous freezing of the liquid when it comes into contact with the cold mould, *i.e.* in the first

period referred to. This thin layer is almost without visible structure, since, owing to the extremely rapid freezing, it yields only very minute crystals, which crystals are considered to be of the same composition as the liquid steel. Progressing inwards will now be found the region of columnar crystals, during the formation of which the heat is still being abstracted from the steel by the walls of the mould, and hence the base of this columnar structure is to be found on the sides and bottom surfaces from which solidification is proceeding. This crystallisation, whilst rapid, is slow enough to be selective, the cores of the solid crystals, as before stated, being presumably purer than the original steel.

One curious effect noticed in steel ingots of all the sizes dealt with in the present Report is that these columnar crystals do not grow inwards in a direction exactly normal to the chill face, as might be expected, but have a definite upward trend, as shown in Fig. 2 (Plate III.). It has been suggested, as a result of experiments with stearine ingots, that this upward direction is given to the crystallites first forming at the chill surface as a consequence of very local outward curvature of the isothermals in the steel at the outer edges of the rising surface. Once this direction has been given, it is continued in each growing columnar crystalline grain. It is interesting to observe that the upward trend is much more marked in wax ingots which have been slowly poured by means of a small nozzle, in the same manner as steel ingots, than in others where the mould has been filled in a few seconds by decanting the molten wax direct from a beaker.

(*c*) The columnar region having formed, the interesting position is reached at which marked heterogeneity begins to be apparent. The liquid steel existing in proximity to the already frozen columnar region is apparently richer in carbon, sulphur, and phosphorus than the original liquid steel. The higher concentration of the elements mentioned in this zone appears to persist in contrast to the average composition of the remaining body of liquid steel, and continues to do so in some degree until solidification of the ingot is complete. As a result of the reactions in the steel-making furnace, there exist to a greater or less degree oxides dispersed through the liquid steel in a more or less colloidal

form. "Manganese sulphide,"[1] which is held to be insoluble in liquid steel, is also dispersed in a similar manner, and it is an interesting and demonstrable fact that, in the region of high concentration adjoining the surface of the columnar growth, the sulphides, as one would expect, and the oxides also, as suggested by some, appear to segregate. As the growth of the columnar crystals proceeds, the degree of the concentration of the oxides in the adjoining liquid steel naturally increases, and zones of segregate become emphasised, and the non-metallic matter coalesces. Some of the segregate and non-metallic matter is entangled in the tips of and between the growing crystals, and some apparently rises by virtue of lower density. When the ascending segregates are impeded by the growing crystals, they tend to elongate and form typical string-like formations of segregate known as "ghost lines." If this description be correct, then the position and the extent of the first zone of segregation will depend upon the depth to which the early columnar crystals are produced, which indeed would seem to be the case.

It has been suggested that, following the formation of the columnar zone, equiaxed crystals of relative purity begin to form in the central portion of the ingot and fall towards the bottom. It results from the relative positions of the liquidus and solidus in the equilibrium diagram for the binary system of iron and carbon or carbide, that if there is a small variation in temperature and composition between the liquid centre and the freezing wall of the ingot, say 20° C., then it is possible while the walls are continually growing at the lower temperature for purer free crystallites to form in the interior liquid at the higher. It further seems reasonable to assume that such crystallites, being perhaps heavier, will tend to settle and become mixed with those growing on the bottom. A central zone purer than the average metal would then be formed in the ingot, and this zone would necessarily be conical in shape. Owing, however, to the absence of sufficient physical data to enable unanimity to be reached as to whether or not it is likely for such crystals to form and fall to the bottom, it is simply put on record that this is one suggestion which has been made, with a view to explaining what is actually found—viz. that the

[1] MnS is here used as an empirical description covering all those inclusions which are largely composed of MnS.

"ghosts," or segregated strings, tend to slope towards the centre of the top of the ingot, simply because such liquid portions of high concentration become trapped between the columnar zone and the centre area of free crystallites which rests on the base; in continuation of which idea it is noted that the inner boundary of the "ghost" zone tends to slope towards the central axis of the ingot as one examines it from the bottom upwards.

(*d*) Whilst the columnar region is being formed the steel is contracting by the general cooling effect. As a result, at a certain stage, governed by the size and nature of the mould, and the nature of the steel, portions of the shell of solid steel separate from the wall of the mould, as is commonly observed in the casting of ingots, and a gap is formed between the two. Up to this point heat has passed outwards through the growing layer of solid steel and the walls of the mould by a continuous process of conduction. As soon as the gap is formed this conduction becomes discontinuous, and cooling takes place practically only by radiation from the ingot to the mould. Under these conditions a marked reduction in the rate of heat transference must occur, and with it a distinct retardation in the rate of freezing of the remaining liquid steel. It is suggested that this factor is largely responsible for the change in the type of crystal from the columnar to the equiaxed type.

It may be thought that the explanation of the change in type of crystallisation, which depends mainly upon the separation of the shell of solid steel from the walls of the mould, is not at all adequate or satisfying. Small test ingots, although necessarily always cooled very rapidly owing to their size, can have, under suitable conditions, principally of casting temperature, a large proportion of equiaxed crystals, as shown by the fracture. What the actual explanation of the critical change from columnar to equiaxed is, it is difficult to say, but casting temperature seems to be in some way a dominant factor. In the explanation mentioned also not enough is perhaps made of the fact that the first solidified portions of the ingot must themselves very greatly slow up the rate of cooling of the remaining fluid steel, as conduction will not go on very readily through steel at such a high temperature; and, further, the liberation of the latent heat of freezing must have a retarding effect.

This change in rate of cooling cannot, however, alter the general nature of the process of freezing. The major portion of the heat from the liquid steel passes out through the walls and base of the solidified steel and mould. The outer layers of liquid in contact with the solidified steel may be considered to be the coldest portion of the remaining liquid, and freezing, however slow, to proceed as previously from the already solid shell, except, for instance, where differential composition in the liquid phase may produce crystals at temperatures above the freezing point of the segregated material. This continuity in the process of freezing is borne out by the example shown in Fig. 3 (Plate IV.), which reproduces the section through an ingot overturned when partially frozen. It must, however, be borne in mind that in very large masses this frozen contour may be modified. In examples placed before the Committee, etched sections from ingots even of large sizes showed a continuation of the columnar crystal axes from the surface to the centre of the ingot, there being no apparent break at the change from the columnar type to the free crystal.

As this crystallisation proceeds on the thickening walls of the ingot, the crystals deposited or growing must still be purer than the liquid steel, and the layer of liquid in contact with this wall must have a higher concentration of those elements in solution than the remaining liquid. This layer of less pure liquid steel will be subject to two tendencies. In the first place, it will tend to rise towards the head of the ingot, owing to its possibly lower density; and, in the second place, the carbon and phosphorus in this layer will tend to diffuse into the remaining liquid steel, a process which will continue for some time after solidification. It is experimentally demonstrable that the former tendency predominates, as examples have been before the Committee in which liquid segregate had clearly arrived in the head of the ingot some considerable time before solidification was complete. Two processes, then, are proceeding simultaneously—the segregate is rising, and the walls of the ingot are growing inwards. It has been suggested that, as a consequence of the segregate rising, there is presumably a responsive downward movement elsewhere. As the segregate rises it will be trapped at various points nearer and nearer to the centre of the ingot by the in-growing crystals as the head of the ingot is approached, thus giving the truncated cone of

segregation. As the rate of cooling falls the speed of crystallisation decreases, the time available for the rising of the segregate will increase, and thus separation from the growing crystals will be more and more complete.

In the upper half of the ingot this purification by separation of the segregate will be more than balanced by the segregate rising from below, and hence the increased concentration of the constituents in this zone.

At a certain stage in the cooling of the freezing ingot, the temperature of the remaining liquid will approach the freezing point and it will become very viscous. The tendency of the segregate to rise will therefore be materially reduced. On the other hand, the liquid steel and segregate remaining in the head will tend to be drawn down the comparatively narrow central channel of remaining liquid steel, to counterbalance the contraction due to loss of temperature. The segregated material will thus be drawn with it, giving rise to the V-shaped zones on the central axis of the ingot, which would explain the sagging effect generally observed. It is well known that the extent to which this occurs depends largely, apart from casting temperature, upon the amount of hot and liquid steel maintained in the head of the ingot for the purpose of filling the cavity which the freezing steel tends to form. The size and shape of the ingot are also variables of considerable influence. It will, of course, be seen that this drawing down of the segregate forms further evidence of the separation of the segregate which must have taken place to permit it to have risen and collected in the upper portion of the ingot.

It will thus be clear that the amount and position of the central segregate can be controlled to some extent by the use of various factors ; on the contrary, the conical segregate seems stereotyped and difficult to mitigate.

From the foregoing it will be evident that the last portion to freeze in the top of the ingot must, of necessity, be richer in segregate, of lower density, and, as naturally follows, of lower melting point.

As regards the unsoundness along the central axis of the ingot and elsewhere, it is suggested that this is due to the meeting of, and loose cohesion between, the differently oriented systems of crystals growing from the walls and base of the mould. These

planes and lines of weakness are associated with planes of segregation, which affords evidence in support of the general view as to the manner in which the heterogeneity comes into existence. If the crystals formed are purer than the mother liquor, and therefore leave a more impure liquid, *i.e.* segregate, on the plane of crystallisation, then whenever two such planes meet there should be, as is indeed found, a collection of segregate. Further, the fact that the central axis is always a zone of looseness or weakness, seems to be direct evidence in favour of the progressive crystallisation from the surface to the centre of the ingot. Such a process would, obviously, leave a central zone of weakness, whereas if the crystallisation were simultaneous throughout the central or free crystal zone, as is supposed by some, there is really no very apparent reason why there should be any central weakness.

Section V.—*Bibliography.*

No reference has been made so far to the work of previous investigators upon the problems involved in the study of the heterogeneity of steel and of the phenomena of segregation and crystallisation. The Committee fully recognises that acknowledgments are due to numerous workers on these subjects, and in particular to the following, whose names are pre-eminently associated with the study of these problems: Brearley, Brinell, Burgess, Charpy, Le Chatelier, Giolitti, Hadfield, Howe, Snelus, Stead, Talbot, Tschernoff, Wahlberg, and Wüst.

The labour, time, and expense which these distinguished metallurgists have devoted to investigations with a view to improving steel are appreciated, and their researches have led to considerable improvement in the art of the manufacture of steel. References to the records of their work are included in the following bibliography, for which the Committee is greatly indebted to Mr. G. C. Lloyd. It contains notices of all important literature since 1903 on the segregation, solidification, crystallisation, piping, and other phenomena associated with the heterogeneity of steel ingots.

The bibliography itself is preceded by an alphabetical index of authors' names to facilitate reference to the different articles and papers, which have been arranged in chronological order, the number or numbers attached to each name representing the running number of the article or articles by the respective authors.

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(The essential part of the process consists in placing a cap on the top of the ingot mould after filling, and a preheated mixture of air and producer-gas is blown through a burner inside the cap on to the surface of the metal in the mould. The top can be kept liquid long enough to enable it to fill any cavity due to shrinkage. The discard is equal to 5 per cent. of the total weight.)

2. ANON.: "Further Development of Riemer's Process for the Production of Sound Ingots." *Stahl und Eisen*, 1904, vol. xxiv. p. 392.

3. J. E. STEAD: "The Segregatory and Migratory Habit of Solids in Alloys and in Steel below the Critical Points." *Jnl. of the Society of Chemical Industry*, 1903, vol. xxii. p. 340; Abstr., *Jnl. I. & S. Inst.*, 1904, No. I. p. 652.

4. A. SAUVEUR and J. WHITING: "Casting of Pipeless Ingots by the Sauveur Overflow Method." *Proc. of American Soc. for Testing Materials*, 1903, vol. iii. p. 129; *Iron & Coal Trades Review*, 1905, vol. lxxi. p. 2114; Abstr., *Jnl. I. & S. Inst.*, 1906, No. I. p. 455.

(The method consists in connecting a number of moulds so that the molten metal can overflow from one mould into the next while pouring is continued in the first mould. The method is probably more applicable to small crucibles than to large ingots.)

5. T. ANDREWS: "Microscopic Observations on Naval Accidents." *Engineering*, 1904, vol. lxxviii. pp. 737, 778, 810; 1905, vol. lxxix. p. 563; vol. lxxx. p. 235; 1906, vol. lxxxi. p. 331.

(This series describes the nature of defects in iron and steel material used in marine engine construction as revealed by a microscopic study. Many of them are found to be due to micro-flaws (inclusions), consisting of slag, sulphides of manganese, and iron.)

6. J. E. STEAD: "Sulphides and Silicates of Manganese in Steel." *Iron and Steel Magazine*, 1905, vol. ix. p. 105; Abstr., *Jnl. I. & S. Inst.*, 1905, No. I. p. 756.

(The nature of inclusions of sulphides and silicates of manganese in steel is discussed, and photomicrographs of these compounds are shown. The cause of the formation of the silicate appears to be the action of oxygen on the stream of molten steel during pouring, leading to the formation of a silicate of manganese, which subsequently becomes entangled in the metal.)

7. H. G. HOWORTH: "Presence of Greenish-Coloured Markings in the Fractured Surfaces of Test-Pieces." *Jnl. I. & S. Inst.*, 1905, No. II. p. 301.

(Describes the nature of inclusions found in large forgings for guns; out of 85 forgings 8 per cent. had these inclusions at the muzzle end, and 11 per cent. at the breech end. Of larger forgings up to 70 tons in weight, 5 per cent. were defective at the muzzle end, and 35 per cent. at the breech end. The greenish markings appeared as streaks. Careful examination of the substances found showed that there were two kinds, sulphide of manganese and silicate of manganese.)

8. F. O. BEIKIRCH: "Method for Prevention of Piping in Large Steel Ingots." *Stahl und Eisen*, 1905, vol. xxv. p. 865; Abstr., *Jnl. I. & S. Inst.*, 1905, No. II. p. 729.

(A method for the prevention of piping in large steel ingots up to 60 tons in weight, used at Sterkrade, consists in placing on the top of the mould a receptacle filled with glowing coke, through which an air-blast passes. This keeps the top of the ingot liquid as long as may be required.)

9. R. M. Daelen: "Method for Prevention of Piping in Steel Ingots." *Stahl und Eisen*, 1905, vol. xxv. p. 923; Abstr., *Jnl. I. & S. Inst.*, 1905, No. II. p. 729.

(The Whitworth and the Harmet methods of liquid compression are described, and special reference is made to Riemer's method of keeping the top of the ingot hot by means of a producer-gas jet.)

10. H. Wedding: "Investigation of the Cause of a Blowhole in a Steel Ingot." *Stahl und Eisen*, 1905, vol. xxv. p. 923; Abstr., *Jnl. I. & S. Inst.*, 1905, No. II. p. 730.

(Investigation of an ingot for a propeller shaft revealed a hollow, 6 inches in diameter, in the upper part. To avoid such defects it is recommended that ingot moulds of cylindrical shape should be used, and that the metal should be cast as hot as possible.)

11. B. Talbot: "Segregation in Steel Ingots." *Jnl. I. & S. Inst.*, 1905, No. II. p. 204.

(The use of aluminium as an addition in the ingot mould for the prevention of segregation is described. The experiments were made on ingots from acid and basic open-hearth furnaces, varying in weight from 1½ to 3½ tons, the effect being to localise segregation of phosphorus and sulphur.)

12. J. Riemer: "Formation of Piping in Steel Ingots and Means for its Prevention." *Stahl und Eisen*, 1906, vol. xxvi. p. 185; Abstr., *Jnl. I. & S. Inst.*, 1906, No. II. p. 455.

(The author describes further developments with his method for the prevention of piping by keeping the top of the ingot liquid, by means of a flame of producer-gas introduced through a cover on the mould. *See* No. 1.)

13. A. J. Capron: "Compression of Steel Ingots in the Mould." *Jnl. I. & S. Inst.*, 1906, No. I. p. 28.

(The author describes the fluid compression of ingots in the mould by the system of Robinson and Rodger. The ingot moulds are divided longitudinally in the centre, a removable packing piece being placed between the halves of the mould. The moulds are held upright in a press; the packing piece is removed when the metal has set, and the pressure is applied to the ingots laterally.)

14. N. Lilienberg: "Piping in Steel Ingots." *Trans. of American Inst. of Mining Engineers*, 1906, vol. xxxvii. p. 238; Abstr., *Jnl. I. & S. Inst.*, 1906, No. I. p. 452.

(The author discusses generally the methods for reducing piping in steel ingots. The addition of aluminium makes somewhat sounder steel, but does not prevent piping. Thermite will make the steel in the mould fairly sound, but cannot prevent piping, although the pipe is somewhat reduced. A clay lining in the top of the mould will shorten the pipe, but the method involves much labour. The various methods of liquid compression are described, and the Illingworth press as modified by Robinson and Rodger is considered to be the most successful.)

15. J. E. Stead: "Crystallisation and Segregation of Steel Ingots." *Proc. of the Cleveland Inst. of Engineers*, 1905–6, p. 163; Abstr., *Jnl. I. & S. Inst.*, 1906, No. I. p. 467; 1906, No. IV. p. 887.

(The nature of segregations in steel ingots, and the manner of their formation, are described. Sulphur segregates the most; phosphorus follows the sulphur; carbon the phosphorus; and manganese and silicon do not appear to segregate to any material extent. High casting temperature tends to produce axial segregation.)

16. A. Wiecke: "Compression of Liquid Steel by the Harmet Process, with Special Reference to the Compressing Plant at the Oberbilk Works." *Zeitschrift des Vereines deutscher Ingenieure*, 1906, vol. l. p. 1279. See also *Jnl. I. & S. Inst.*, 1902, No. II. p. 146.

17. A. Ruhfus: "Occurrences in Steel Melting." *Stahl und Eisen*, 1906, vol. xxvi. p. 775; Abstr., *Jnl. I. & S. Inst.*, 1906, No. IV. p. 878.

(The causes of the presence of gas in steel are investigated. From samples taken during the open-hearth boil at intervals of 15 minutes, and rapidly cooled in moulds, it is found that, as the temperature rises and the steel becomes more fluid, the blowholes concentrate towards the centre, and gradually grow smaller in number, disappearing entirely in the finished metal. The gas from fluid low-carbon open-hearth steel was found to consist of 27 per cent. maximum of hydrogen and 52 per cent. maximum of carbon monoxide.)

18. C. L. Huston: "Experiments on the Segregation of Steel Ingots in its Relation to Plate Specifications." *Proc. of the American Soc. for Testing Materials*, 1906, vol. vi. p. 182.

(The paper is written mainly for the information of engineers and users of steel as to the position of segregation in ingots, and the effect on finished products. The results of tensile tests and analyses show how the steel varies throughout the different parts of the ingot.)

19. R. Fischer: "A New Process at the Gutehoffnungshütte for obtaining Ingots Free from Pipe." *Giesserei Zeitung*, 1906, vol. iii. p. 738; Abstr., *Jnl. I. & S. Inst.*, 1907, No. I. p. 509.

(A hollow cover is placed on the top of the ingot mould. Before filling the mould, the cover is filled with coke, and lighted, openings being provided through which the hot gases enter the mould. After filling the mould a blast of cold air is turned on, which penetrates the incandescent column of coke, mixes with the gas, enters the space above the metal, and develops sufficient heat to keep the top of the ingot liquid as long as required.)

20. W. Kusl: "Blowholes and Piping in Steel Ingots." *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, 1906, vol. liv. pp. 593, 610; Abstr., *Jnl. I. & S. Inst.*, 1907, No. I. p. 510.

(The origin of blowholes is considered. The reaction theory attributes their formation to gases due to reactions in the metal; the absorption theory to gases taken up mechanically and entangled. Carbon monoxide is the chief cause of blowholes. Hydrogen and nitrogen are taken up from the air during pouring.)

21. H. M. Howe: "Piping and Segregation in Steel Ingots." *Trans. American Inst. of Mining Engineers*, 1907, vol. xxxviii. p. 3; Abstr., *Jnl. I. & S. Inst.*, 1907, No. I. p. 520.

(Investigation of the causes of pipe and segregation. It is concluded that the pipe is shortened and segregation raised: (1) By top-casting instead of bottom-casting; (2) by slow casting; (3) by casting with large end up; (4) by retarding the cooling of the top by means of a sinking head or otherwise; (5) by liquid compression; (6) by permitting deep-seated blowholes to form through adjusting the quantity of silicon and manganese or their equivalents. The pipe is shortened and segregation probably increased: (7) by casting in wide ingots (of large cross-section); (8) by using moulds of low conducting power, *i.e.* lined with sand or clay; (9) by using preheated moulds. Segregation is restrained by casting as cool as possible, and by casting in small ingots.)

22. A. Obholzer : " On the Avoidance of Piping in Ingots." *Jnl. of the Franklin Inst.*, 1907, vol. clxiv. p. 1 ; *Stahl und Eisen*, 1907, vol. xxvii. pp. 1117, 1155 (from the Hungarian) ; Abstr., *Jnl. I. & S. Inst.*, 1907, No. III. p. 465.

(Describes methods for diminishing piping in steel ingots at the Hungarian Government Works at Diosgyor. Considerable improvement was effected by the use of thermite. Gives illustrations of ingots cast with and without addition of thermite in the mould. The advantages over the Harmet process are that, while the result is nearly as good, the very costly plant is saved.)

23. E. F. Law : " The Non-Metallic Impurities in Steel." *Jnl. I. & S. Inst.*, 1907, No. II. p. 94.

(Microscopical examination shows that in commercial steel five distinct impurities may be present in the form of inclusions—namely, sulphide of iron, sulphide of manganese, silicate of iron, silicate of manganese, and oxide of iron (or possibly oxide of manganese). These do not occur in a pure state, but their composition is mainly that of the compound named. Sulphide of iron is rarely met with, being present only when sulphur is very high and manganese low. Sulphide of manganese is invariably found in steel, being the form in which sulphur occurs in all good steel. Manganese silicate and iron silicate are very injurious, and cannot be detected by analysis, but only by microscopical examination.)

24. E. von Maltitz : " Blowholes in Steel Ingots." *Trans. of American Inst. of Mining Engineers*, 1907, vol. xxxviii. p. 412 ; Abstr., *Jnl. I. & S. Inst.*, 1907, No. III. p. 465.

(Discusses Howe's conclusions (*Am.I.M.E. Trans.*, vol. xxxviii.) and gives results of investigation of gases in blowholes. Hydrogen ranges from 16·2 to 54·2 per cent., nitrogen from 2·2 to 36·7 per cent., carbon monoxide from 18·1 to 68 per cent. A proportion of carbon dioxide is also present. The source of CO is the ferrous oxide dissolved by the steel during manufacture, and the solvent power increases with the temperature. To avoid blowholes, the heat should be kept at a medium temperature during the last period before teeming; the finishing slag should not be too rich in oxygen, and should be properly fluid ; the ferrous oxide should be destroyed by stirring before teeming.)

25. E. L. Zalinski : " Compression of Steel by Wire-Drawing during Solidification in the Ingot Mould." *Jnl. of the U.S. Artillery ; Iron Trade Review*, 1907, vol. xli. p. 300.

(Describes the results obtained with the Harmet process.)

26. A. Wiecke : " The Production of Steel Ingots for Large Crankshafts." *Iron & Coal Trades Review*, 1907, vol. lxxv. pp. 1759, 1857.

(Translation of author's previous paper on compression of ingots by the Harmet process. *See* No. 16.)

27. H. M. Howe and B. Stoughton : " Influence of the Conditions of Casting on Piping and Segregation as shown by Wax Ingots." *Trans. of American Inst. of Mining Engineers*, 1907, vol. xxxviii. p. 109 ; Abstr., *Jnl. I. & S. Inst.*, 1907, No. III. p. 483.

(Segregation phenomena are studied in the light of the behaviour of wax ingots.)

28. H. M. Howe: "A Further Study in the Segregation in Steel Ingots." *Engineering & Mining Jnl.*, 1907, vol. lxxxiv. p. 1011; Abstr., *Jnl. I. & S. Inst.*, 1908, No. I. p. 377.

(Between the limits of $2\frac{1}{4}$ inches and 16 inches square the influence of size of ingot on the degree of segregation is so slight as to be almost masked by other variables, though there are indications that large size (30 inches or more across) increases segregation. There is more segregation in ingots cooled quickly than in those cooled slowly. The most enriched part lies in the axis of the ingot usually at between 6 and 28 per cent. of the length of the ingot from the top.)

29. J. E. Stead: "Segregation in Steel." *Inst. of Civil Engineers, Engineering Congress*, 1907, Section IV. p. 94; Abstr., *Jnl. I. & S. Inst.*, 1907, No. III. p. 485.

(Summary of the knowledge of the concentration of metalloids in steel ingots, and of the effect of segregation on the physical properties of the finished steel.)

30. J. O. Arnold: "Factors of Safety in Marine Engineering." *Trans. of Inst. of Naval Architects*, 1908, vol. v. p. 260; Abstr., *Jnl. I. & S. Inst.*, 1908, No. I. p. 359.

(Discusses methods of reducing segregation in large ingots. The only trustworthy and practical way to do this is to cool the ingot under fluid compression.)

31. H. Fay: "A Microscopic Investigation of Broken Steel Rails; Manganese Sulphide as a Source of Danger." *Proc. of American Soc. for Testing Materials*, 1908, vol. viii. p. 74.

(When manganese sulphide is found in combination with a hardened surface, cracks will develop through the sulphide and through the hard metal on the surface. Manganese sulphide is dangerous if it occurs in the form of flattened elongated masses instead of in threads.)

32. G. Belloc: "Gases Occluded in Steels." *Comptes Rendus*, 1908, vol. cxlv. p. 1280; *Revue de Métallurgie*, 1908, vol. v. p. 469; Abstr., *Jnl. I. & S. Inst.*, 1908, No. I. p. 399; 1908, No. III. p. 650.

(Turnings of a mild steel (0·12 per cent. carbon and 0·35 per cent. manganese) were heated for several days and the gases extracted. The rate of evolution was at a minimum at 200° C., and reached a maximum between 400° and 600°, falling again to a minimum on passing the point A2. After A3 the rate of evolution rose continuously as temperature increased, and at 1200° a volume of gas equal to twelve times that of the steel had been extracted. Up to 400° the gas was almost entirely CO_2, which disappeared at 550°. Above 400° hydrogen and CO were given off, and at 550° nitrogen, up to 10 per cent. of the total gas, appeared.)

33. G. Belloc: "Gases Occluded in a Special Nickel Steel." *Revue de Métallurgie*, 1908, vol. v. p. 571; Abstr., *Jnl. I. & S. Inst.*, 1908, No. III. p. 649.

(The nickel steel contained 45 per cent. nickel and 0·15 per cent. carbon. The evolution of gas with the rise of temperature was regular. The kind of gases was the same as recorded above.)

34. N. Lilienberg: "Compression of Semi-Liquid Steel Ingots." *Jnl. of Franklin Institute*, 1908, vol. cxlv. p. 121; Abstr., *Jnl. I. & S. Inst.*, 1908, No. I. p. 360.

(Advocates stripping the ingots before solidification, and compressing a number of them together in a special framework.)

35. B. Osann: "The Harmet Process as used at the Open-Hearth Works 'Deutscher Kaiser' at Bruckhausen." *Stahl und Eisen*, 1908, vol. xxviii. p. 1601; Abstr., *Jnl. I. & S. Inst.*, 1909, No. I. p. 619.

(A description of the Harmet process for fluid compression of steel. The average elongation of the pressed steel is 17·7 per cent., as compared with 12·9 per cent. of the unpressed.)

36. F. Beutter: "Development of the Process of Compressing Steel by Wire-Drawing." *Revue de Métallurgie*, 1909, vol. vi. p. 75; Abstr., *Jnl. I. & S. Inst.*, 1909, No. I. p. 618.

(Analyses of many different portions of the compressed ingots indicate the improved homogeneity. A list of steelworks using the Harmet process is given.)

37. Anon.: "5000-ton Press for Dynamic Compression of Fluid Steel." *Engineering*, 1909, vol. lxxxvii. p. 101; Abstr., *Jnl. I. & S. Inst.*, 1909, No. I. p. 619.

(The Harmet press and method of operation at Beardmore's Works are described, and the homogeneity of the ingots is illustrated by photos.)

38. P. H. Dudley: Discussion of Howe's paper on Piping and Segregation. *Trans. of American Inst. of Mining Engineers*, 1908, vol. xxxix. p. 818; Abstr., *Jnl. I. & S. Inst.*, 1908, No. III. p. 629.

(Confirms Howe's observations. Teeming with small-sized nozzle is conducive to production of sound ingots. In large ingots segregation is intensified and more harmful than in those of smaller dimensions.)

39. H. M. Howe, W. Campbell, and W. T. Koken: "Can Ingotism be Cured by Prolonged Exposure to the Temperature at which Overheating is Cured?" *Proc. of American Soc. for Testing Materials*, 1908, vol. viii. p. 185; Abstr., *Jnl. I. & S. Inst.*, 1909, No. II. p. 473.

(Ingotism is the extremely coarse structure which exists in unannealed ingots and steel castings. It is recognised by the white network of primaustenoid, the network, spines, and other masses rich in ferrite and therefore poor in carbon, which persist as undiffused relics of the primary austenite formed in the original solidification of the molten steel. The coarse ferrite network caused by overheating at 1377° C. is effaced rapidly by heating between 804° and 840°, but the primaustenoid network is not completely effaced by long exposure to this temperature. It requires heating at between 1180° and 1194° to cure ingotism rapidly.)

40. W. Rosenhain: "Slag Enclosures in Steel." *Proc. of the International Assoc. for Testing Materials*, 1909, vol. i.

(Origin of enclosures. Tensile tests do not reveal their influence, but if material undergoes transverse stresses, or is subjected to shock vibration, the enclosures will fracture and form an internal fissure.)

41. T. Baker: "Gases Occluded in Steel." *I. & S. Inst.: Carnegie Scholarship Memoirs*, 1909, vol. i. p. 219.

(Reviews work of previous investigators, giving short bibliography (p. 229). Describes experiments made to ascertain nature and volume of gases given off when steel is heated *in vacuo*, to discover relation between critical points and the extent of evolution of gases, and the part played by these gases in the production of blowholes. Two small ingots of crucible steel, 6 centimetres square, were made, from which specimens 6 centimetres long and 1 centimetre square were cut. Aluminium was added to one ingot, the other was untreated. The specimens were heated in a

vacuum tube furnace, and evolution of gas at different temperatures noted. The maximum evolution took place at 688° in the aluminium-treated steel, and at 681° to 696° in the untreated. The total gas from the aluminium-treated (containing no blowholes) was 91·86 cubic centimetres, of which 47·77 cubic centimetres was hydrogen and 41·83 cubic centimetres was CO. The total gas from the untreated steel (with blowholes) was 42·09 cubic centimetres, of which 22·99 cubic centimetres was hydrogen and 17·85 cubic centimetres CO.)

42. J. F. Springer: "The Harmet Process of Ingot Compression." *Iron Age*, 1909, vol. lxxxiii. p. 2002; Abstr., *Jnl. I. & S. Inst.*, 1909, No. II. p. 484.

(Micrographs of structures, and tensile tests on specimens from compressed and uncompressed ingots.)

43. H. Fay and R. W. G. Wint: "Further Investigations of Broken Steel Rails." *Proc. of American Soc. for Testing Materials*, 1909, vol. ix. p. 77; Abstr., *Jnl. I. & S. Inst.*, 1909, No. II. p. 497.

(Results of examination of fractured rails. Failure was due to segregation of slag concentric with the section; remnants of slag were found in the split portion of rail heads. Lower sulphur should be specified and more time allowed between adding FeMn and teeming. Bottom-pouring is recommended.)

44. P. H. Dudley: "Dark Carbon Streaks in Segregated Metal in Split Heads of Rails." *Proc. of American Soc. for Testing Materials*, 1909, vol. ix. p. 98; Abstr., *Jnl. I. & S. Inst.*, 1909, No. II. p. 497.

(Investigations of cause of split rail heads. Dark carbon streaks were found in neighbourhood of split, with much higher percentage of carbon than average carbon in the rail itself. The streaks are not an ordinary segregation effect. Examination shows that the bottom plates of ingot moulds after a number of heats had lost 30 to 40 lbs. in weight, and this loss seems to occur when the steel is teemed at high temperature.)

45. H. M. Howe: "The Closing of Blowholes in Steel Ingots." *Proc. of American Soc. for Testing Materials*, 1909, vol. ix. p. 327.

(Conclusions as to the conditions under which blowholes and cavities are formed in steel ingots.)

46. H. M. Howe: "Influence of Ingot Size on the Degree of Segregation in Steel Ingots." *Trans. American Inst. of Mining Engineers*, 1909, vol. xl. p. 644; Abstr., *Jnl. I. & S. Inst.*, 1910, No. I. p. 678.

(A diagram shows the average degree of enrichment in 49 different ingots, classed according to size. Enrichment in sulphur is greatest, in phosphorus next, and in carbon next. The effect of ingot size is slight until a section 20 inches square is reached, and beyond that enrichment increases more rapidly.)

47. H. M. Howe: "The Closing and Welding of Blowholes in Steel Ingots." *Report of Brit. Assoc., Sheffield Meeting*, 1910, p. 563; Abstr., *Jnl. I. & S. Inst.*, 1910, No. II. p. 504.

(Reabsorption of gases in blowholes and the welding of blowholes ought to be promoted by reheating rather than by direct rolling.)

48. G. Tagueeff: "The Homogeneity of Metals." *Jnl. I. & S. Inst.*, 1910, No. I. p. 467.

(The paper deals with failure and wear of rails as influenced by the non-homogeneity of the material. There is no reference to ingot casting and treatment.)

49. G. Auchy: "Mechanically held Impurities in Steel." *Iron Age*, 1910, vol. lxxxv. p. 108; Abstr., *Jnl. I. & S. Inst.*, 1910, No. I. p. 678.

(To free steel from oxides, silicates, sulphides, and other enclosures, it should be kept liquid for a considerable time in a refractory-lined mould and in a reducing atmosphere.)

50. S. S. Knight: "Segregation of the Various Metalloids in Steel." *Iron Trade Review*, 1910, vol. xlvi. pp. 475, 926; Abstr., *Jnl. I. & S. Inst.*, 1910, No. I. p. 677; 1910, No. II. p. 506.

(Illustrations are given of a cold-poured and a hot-poured ingot, from which it appears that the slow cooling which is supposed to prevent segregation does so only with certain elements. Sulphur, phosphorus, and copper show the greatest tendency to segregation. It is believed that all the sulphur in steel is in the form of iron sulphide, of the composition FeS.)

51. von Paravacini: "The Reduction of Piping." *Stahl und Eisen*, 1910, vol. xxx. p. 215; Abstr., *Jnl. I. & S. Inst.*, 1910, No. I. p. 657.

(A crucible is filled half with finely broken coke and half with silver sand, heated in a furnace, and is inverted over the top of the ingot mould as soon as teeming is complete. The sand comes in contact with the metal, and is itself covered by the coke, thus helping the metal to retain its heat, the radiated heat being replaced by heat from the incandescent coke. The discard is said to be reduced by 40 per cent.)

52. P. L. T. Héroult: "Presence and Influence of Gases in Steel." *Trans. of American Electrochemical Soc.*, 1910, vol. xvii. p. 135; Abstr., *Jnl. I. & S. Inst.*, 1910, No. II. p. 504.

(Blowholes are the result of the disengagement of CO, which does not pre-exist in steel, but is produced when it cools down and begins to solidify, due to the reducing action of carbon on iron protoxide.)

53. E. Goutal: "Study of Gases Evolved by the Action of Cuprous Salts on Steel." *Revue de Métallurgie*, 1910, vol. vii. p. 6; Abstr., *Jnl. I. & S. Inst.*, 1910, No. II. p. 505.

(An investigation of the nature of gases occluded in steel, as ascertained by the action of cuprous salts on steel.)

54. F. Wüst and H. L. Felser: "Influence of Segregation on the Strength of Mild Steel." *Proc. of Internat. Congress of Mining, Metallurgy, &c., Düsseldorf*, 1910; *Metallurgie*, 1910, vol. vii. p. 363; Abstr., *Jnl. I. & S. Inst.*, 1910, No. II. p. 506.

(The tendency of sulphur and phosphorus to segregate is greater than that of carbon, copper, and manganese. The larger the ingot the more readily the sulphur segregates. Shock tests reveal the effect of segregation much better than tensile tests.)

55. G. B. Waterhouse: "Influence of Titanium on Segregation in Bessemer Rail Steel." *Proc. of American Soc. for Testing Materials*, 1910, vol. x. p. 201; Abstr., *Jnl. I. & S. Inst.*, 1910, No. II. p. 506.

(Titanium used as a deoxidiser retards segregation of sulphur, phosphorus, and carbon in normally quiet quick-setting acid Bessemer steel.

56. P. H. DUDLEY: "The Use of Ferro-Titanium in Bessemer Rails." *Jnl. of Industrial and Engineering Chemistry*, vol. ii. p. 299; Abstr., *Jnl. I. & S. Inst.*, 1910, No. II. p. 518.

(The use of ferro-titanium as a deoxidiser improves the quality of the acid Bessemer steel. Iron oxides are reduced and some nitrogen is eliminated.)

57. H. M. HOWE: "The Welding of Blowholes in Steel." *Proc. of American Soc. for Testing Materials*, 1910, vol. x. p. 167; Abstr., *Jnl. I. & S. Inst.*, 1911, No. I. p. 636.

(Specific gravity tests on pieces cut from an ingot and from a plate subsequently rolled from the same ingot show that blowholes must have closed up. An examination of the plate for seams showed the longest seam to be 0·06 inch, and many not over 0·02 inch.)

58. M. MATWEIEFF: "Nature of the Slags Enclosed in Basic Bessemer Steel." *Revue de Métallurgie*, 1910, vol. vii. p. 848; Abstr., *Jnl. I. & S. Inst.*, 1911, No. I. p. 946.

(An investigation of the nature of slag inclusions in basic steel. Small quantities of phosphates of calcium, magnesium, manganese, and iron were enclosed in small steel cylinders, which were heated to 1300° C. The phosphates of magnesium, iron, and manganese were reduced and formed iron phosphide.)

59. H. D. HIBBARD: "The Solid Non-Metallic Impurities in Steel (Sonims)." *Trans. American Inst. of Mining Engineers*, 1910, vol. xli. p. 803; Abstr., *Jnl. I. & S. Inst.*, 1911, No. II. p. 609.

(The nature and composition of solid non-metallic impurities in steel are discussed, and the possible combinations of substances which may form such impurities are enumerated.)

60. J. E. STEAD: "Notes on the Welding up of Blowholes and Cavities in Steel Ingots." Part I., *Jnl. I. & S. Inst.*, 1911, No. I. p. 54; Part II., *Jnl. I. & S. Inst.*, 1912, No. I. p. 104.

(Experiments made in drilling and plugging steel bars show that when two metallic surfaces quite free from oxide or any other foreign matter are brought into contact and forged at about 1100° C. they weld up completely. If blowholes in ingots are subcutaneous, and the ingot is rolled or forged at 1000° C., the cavities weld up, unless they contain foreign matter. Pipe cavities cannot be so readily welded up, as their walls often become coated with oxide scale. Howe's views concerning the cause of the formation of blowholes are stated.)

61. B. OSANN: "Piping in Steel Ingots." *Stahl und Eisen*, 1911, vol. xxxi. p. 673; Abstr., *Jnl. I. & S. Inst.*, 1911, No. II. p. 609.

(Causes of piping are explained.)

62. C. V. SLOCUM: "Titanium in Steel." *Trans. American Foundrymen's Association*, 1912, vol. xx. p. 71 [73]; Abstr., *Jnl. I. & S. Inst.*, 1911, No. II. p. 626.

(Discusses the use of titanium in basic open-hearth practice for removal of brittleness and blowholes.)

63. L. Cubillo : "Manufacture and Treatment of Steel for Guns." *Jnl. I. & S. Inst.*, 1912, No. I. p. 297.

(Discusses casting and treatment of large ingots for gun forgings. Design of ingot moulds. *See also* discussion by J. M. Gledhill, *ibid.* p. 331.)

64. Sir R. A. Hadfield : "Method of Producing Sound Ingots." *Jnl. I. & S. Inst.*, 1912, No. II. p. 11.

(The author's method for producing sound steel consists in the use of a sand-lined sinking head on top of the mould in which the steel is maintained liquid by the combustion of solid fuel (charcoal or coke) by means of a blast of compressed air, a layer of cupola slag being interposed between the liquid steel and the incandescent fuel. The slag largely prevents radiation of heat. The discard is said to amount to not more than 7 per cent. of the ingot. The results of the application of the method to ingots of various sizes and compositions are fully illustrated and described.)

65. Sir R. A. Hadfield : "A New Method of Revealing Segregation in Steel Ingots." *Jnl. I. & S. Inst.*, 1912, No. II. p. 40.

(An ingot $2\frac{1}{2}$ inches square and 30 inches long was cast in a mould in the ordinary way; the composition being carbon 0·41 per cent., silicon 0·53 per cent., manganese 1·32 per cent. The ingot was furnished with a sand-head. A few ounces of molten copper were poured into the centre of the metal in the sand-head about 30 seconds after teeming. On cutting the ingot longitudinally it was found that the copper had penetrated for nearly the full length of the ingot into those portions where piping usually takes place. The experiments were continued with 6-inch ingots, $3\frac{1}{2}$ feet long, with the same result. Finally an ingot 14 inches diameter had 28 lbs. of copper poured into it 15 minutes after casting, and the copper penetrated to within 9 inches of the bottom, showing that the interior remains liquid for quite a considerable time.)

66. H. Goldschmidt : "A New Method for the Improvement of the Soundness of Steel Ingots by the Aid of Thermit." *Jnl. I. & S. Inst.*, 1912, No. II. p. 78.

(Describes the process put into practical operation by Canaris, by which steel, to which no silicon has been added, is rendered sound by plunging a canister containing thermit right to the bottom of the mould immediately after teeming. An iron rod is used to thrust the canister down. For ingots from 3·5 to 8 tons, the weight of the thermit addition is 2·5 kilogrammes. In nine months nearly 18,000 ingots had been treated in this way, the uniformity of product being greatly increased and the discard reduced to a minimum.)

67. K. Troubine : "Observations on Surface Blisters in Steel Ingots." *Revue de Métallurgie*, 1912, vol. ix. p. 127; Abstr., *Jnl. I. & S. Inst.*, 1912, No. I. p. 559.

(Surface defects on ingots are often due to splashes of the metal adhering to the walls of the mould during pouring. At the Oboukhoff Works a sheet-iron funnel suspended on three chains was lowered into the mould and gradually raised as the metal was poured through it. The splashes struck the funnel sides instead of the wall of the mould.)

68. C. Canaris : "Use of Anti-Piping Thermit in Steel Ingots." *Stahl und Eisen*, 1912, vol. xxxii. p. 303; *Iron Trade Review*, 1912, vol. l. p. 701; Abstr., *Jnl. I. & S. Inst.*, 1912, No. I. p. 560.

(Describes his method of plunging a box containing thermit into the liquid ingot. *See* Goldschmidt, No. 66.)

69. E. Heyn and O. Bauer: "Note on Segregation in Steel." *Stahl und Eisen*, 1912, vol. xxxii. p. 402; Abstr., *Jnl. I. & S. Inst.*, 1912, No. I. p. 560.

(Results of examination of a steel tube. The inner part of the wall had an abnormally high sulphur and phosphorus content.)

70. G. B. Waterhouse: "Titanium and Low Carbon Basic Steel." *Iron Age*, 1911, vol. lxxxviii. p. 1306; Abstr., *Jnl. I. & S. Inst.*, 1912, No. II. p. 555.

(The effect of titanium when used as a deoxidiser is to give a solid clean steel, of good uniformity.)

71. C. Canaris: "Influence of Teeming on the Quality of Steel Ingots." *Stahl und Eisen*, 1912, vol. xxxii. pp. 1174, 1264; Abstr., *Jnl. I. & S. Inst.*, 1912, No. II. p. 563.

(Discusses means of avoiding piping and blowholes.)

72. J. Corbiau: "New Method of Casting Steel Ingots." *Revue de Métallurgie*, 1912, vol. ix. p. 532; Abstr., *Jnl. I. & S. Inst.*, 1912, No. II. p. 564.

(The Defays-Lanser process for the multiple casting of small ingots is described. A series of slabs, each grooved on both sides so as to form a number of half moulds, are placed so that the grooves register with one another, thus forming complete moulds kept in position by a hydraulic ram.)

73. E. Heyn and O. Bauer: "Effectiveness of the Harmet Process for making Sound Ingots." *Mitteilungen a. d. Kgl. Materialprüfungsamt, Gross-Lichterfelde*, 1912, vol. xxx. p. 1; Abstr., *Jnl. I. & S. Inst.*, 1912, No. II. p. 565.

(A very exhaustive examination of the effect of compressing ingots by the Harmet process. The tensile properties are improved, and piping, blowholes, and segregation are prevented.)

74. A. Diefenthaler: "Causes of Piping and its Relation to Shrinkage and Composition." *Stahl und Eisen*, 1912, vol. xxxii. p. 1813; Abstr., *Jnl. I. & S. Inst.*, 1913, No. I. p. 636.

(Piping is due to internal shrinkage. The effect of varying the quantity of silicon and other deoxidisers on the density of steel ingots is considered.)

75. E. G. Grace: "Ordnance Manufacture at South Bethlehem." *Iron Age*, 1912, vol. xc. p. 1032; Abstr., *Jnl. I. & S. Inst.*, 1913, No. I. p. 652.

(Method of manufacturing projectiles, armour plate, and guns at South Bethlehem. All large ingots are fluid-compressed. The article deals chiefly with the processes of further manufacture.)

76. F. Pacher: "The Various Kinds of Slag Inclusions in Steel, the Causes of these, and Methods for their Prevention." *Stahl und Eisen*, 1912, vol. xxxii. p. 1647; Abstr., *Jnl. I. & S. Inst.*, 1913, No. I. p. 655.

(Describes the nature of slag inclusions in steel, with suggestions as to cause of their occurrence.)

77. G. Mars: "Determinations of the Nature of Slag Inclusions in Steel." *Stahl und Eisen*, 1912, vol. xxxii. p. 1557.

(Many photomicrographs of slag inclusions are shown.)

78. F. Fischer: "Slag Inclusions." *Stahl und Eisen*, 1912, vol. xxxii. p. 1563.

(Deals with chemical aspect of inclusions.)

79. J. B. Nau: "Defects in Steel Ingots and Steel Rails." *Iron Age*, 1912, vol. xc. p. 398; Abstr., *Jnl. I. & S. Inst.*, 1913, No. I. p. 634.

(Describes the teeming of large ingots with the aid of a tun-dish (called "pouring basket"). The device is said to have been first used at Creusot.)

80. B. Talbot: "The Production of Sound Steel by Lateral Compression of the Ingot whilst its Centre is Liquid." *Jnl. I. & S. Inst.*, 1913, No. I. p. 30.

(Describes his method of stripping ingots of 25 × 25 inches twenty-five to thirty minutes after pouring, and passing them immediately through reversing rolls, compressing them to about 18 or 19 inches square. Many analyses taken along the length and across the face of divided ingots are given showing improvement in homogeneity. Segregation is shown to have formed all along the inner wall of the envelope which solidified before rolling.)

81. B. Talbot: "The Production of Solid Steel Ingots." Pp. 400–423, 481–515. *See* No. 80.

Sir R. A. Hadfield: "Plant for Hadfield Method of Producing Sound Steel Ingots." Pp. 473–480, 481–515. *See* No. 64.

E. A. Beck: "The Use of Anti-Piping Thermit in Casting Steel Ingots." Pp. 453–460, 481–515. *See* No. 66.

E. Gathmann: "Commercial Production of Sound Steel Ingots." Pp. 461–472, 481–515. *See* No. 96.

P. H. Dudley: "Piping and Segregation of Ingots of Steel, and Ductility Tests for Open-Hearth Steel Rails." Pp. 424–452.

(These five papers are contained in *Trans. American Inst. of Mining Engineers*, 1913, vol. xlv.; Abstr., *Jnl. I. & S. Inst.*, 1913, No. I. pp. 631, 632.)

82. E. Houbaer: "Two New Methods of Obtaining Sound Ingots." *Revue Universelle des Mines*, 1913, Series V., vol. i. p. 244; Abstr., *Jnl. I. & S. Inst.*, 1913, No. I. p. 632.

(Criticises the Talbot method of lateral compression of ingots while still liquid in centre. Experience at Cockerill disagrees with Talbot's conclusions. Aluminium was added as a deoxidiser to ingots of 2 to 3 tons, which were afterwards compressed according to Talbot's method. The rails rolled from these ingots showed greater brittleness than those made by the normal process.)

83. L. E. Howard: "The Production of Sound Steel Ingots." *Iron Age*, 1913, vol. xci. p. 995; Abstr., *Jnl. I. & S. Inst.*, 1913, No. I. p. 635.

(Ingots of less than 1 ton were laterally compressed in a hydraulic press while internally fluid. Saw blades manufactured from top or bottom part of the ingots were of equally good quality.)

84. J. E. Stead: "When Steel Freezes." *Proc. of the Cleveland Institution of Engineers*, Session 1912–13, p. 33.

(Paper divided under four heads: A general explanation of what occurs when liquid steel changes from the liquid to the solid state; the nature of the gases in cavities and blowholes and what they teach us, and the conditions necessary to avoid the evolution of gases during freezing; blisters in sheets; and the study of the fracture of a large honeycombed ingot.)

85. G. AUCHY: "The Next Improvement in Steel-Making." *Iron Age*, 1913, vol. xci. p. 239; Abstr., *Jnl. I. & S. Inst.*, 1913, No. I. p. 635.

(Advocates killing the steel in the mould by holding it fluid by means of electric arcs in the covers of the mould.)

86. ANON.: "Jarring Ingot Moulds to Prevent Piping." *Iron Age*, 1913, vol. xcii. p. 399; Abstr., *Jnl. I. & S. Inst.*, 1913, No. II. p. 626.

(The Lash method consists of pouring fluid metal into a mould of great strength and lifting the mould repeatedly and dropping it upon a solid surface. Or the mould can be held and violent blows struck against the bottom to secure the same result.)

87. P. IVANOW: "Experiments with a View to the Elimination of Piping in Steel." *Stahl und Eisen*, 1913, vol. xxxiii. p. 413; Abstr., *Jnl. I. & S. Inst.*, 1913, No. II. p. 626.

(The effect of using a sinking head of suitable proportions was to confine the pipe entirely within the head.)

88. M. H. WICKHORST: "Influence of Titanium on Bessemer Steel." *Iron Trade Review*, 1913, vol. lii. p. 801; Abstr., *Jnl. I. & S. Inst.*, 1913, No. II. p. 627.

(The use of titanium as a deoxidiser in the acid Bessemer converter prevents segregation and honeycombing, but enlarges and deepens the pipe. Inclusions occur lower down than in untreated steel.)

89. E. F. LAKE: "Titanium as Used in Steel-Making." *Metallurgical and Chemical Engineering*, 1913, vol. xi. p. 144; Abstr., *Jnl. I. & S. Inst.*, 1913, No. II. p. 627.

(Describes practice in the use of ferro-titanium as a deoxidiser. The ferro-alloy generally contains 10 to 20 per cent. titanic acid. Segregation is said to be entirely avoided by its use.)

90. M. H. WICKHORST: "Influence of Silicon on Open-Hearth Ingots." *Iron Trade Review*, 1913, vol. lii. p. 804; Abstr., *Jnl. I. & S. Inst.*, 1913, No. II. p. 628.

(Tests show that, by adding silicon, honeycombing is reduced, the pipe is increased, and segregation is lessened.)

91. ANON.: "Shrinkage and Piping of Steel." *Stahl und Eisen*, 1913, vol. xxxiii. p. 675; Abstr., *Jnl. I. & S. Inst.*, 1913, No. II. p. 628.

(A general review of the phenomenon of shrinkage and solidification of steel ingots and the mode in which it takes place.)

92. N. PETINOT: "Segregation and Deoxidation, and the Efficiency of Aluminium, Silicon, and Titanium as Deoxidisers." *Metallurgical and Chemical Engineering*, 1913, vol. xi. p. 231; Abstr., *Jnl. I. & S. Inst.*, 1913, No. II. p. 629.

(Discusses relative efficiency of aluminium, silicon, and titanium as deoxidisers. Aluminium is the most powerful, but alumina forms and is infusible. Silicon is not powerful, and is found in steel after addition. Titanium is the only one which has the advantage of leaving no products of its oxidation in the bath.)

93. DEMOLE: "Segregation in Steel Ingots." *Comptes Rendus de la Société de l'Industrie Minérale*, 1913, p. 329; Abstr., *Jnl. I. & S. Inst.*, 1913, No. II. p. 629.

(The various known methods for the avoidance of segregation are enumerated and briefly described.)

94. ANON. : "A Large Steel Ingot." *Engineer*, 1913, vol. cxv. p. 612.

(Illustration and description of large open-hearth ingot cast by Cammell Laird. Said to be the largest ever cast. Weight, 150 tons; 24 feet 6 inches long, 7 feet 6 inches over corners, 7 feet 1 inch over flats.)

95. M. H. WICKHORST : "Rail Failures and their Causes." *Proc. American Soc. for Testing Materials*, 1913, vol. xiii. p. 582; Abstr., *Jnl. I. & S. Inst.*, 1913, No. II. p. 672.

(Most rail failures are attributable to excessive segregation in the ingot. The remedy would be to increase the discard or to make sufficient use of silicon, titanium, or aluminium.)

96. E. GATHMANN : "Commercial Production of Sound Ingots." *Jnl. I. & S. Inst.*, 1913, No. II. p. 281.

(The method depends on the design of mould. A thick-walled mould is used, with a thin insulated top, the thick walls extending for about 80 per cent., and the thin wall for about 20 per cent., of the length of the mould. The inside tapers sharply at the bottom, and the bottom is fitted with a plug projecting through the foundation stool, the whole being placed on a bogie. From the tapered part the walls are practically parallel, with a slight outward taper beginning at 15 to 20 per cent. from the top. The advantage is in the rapid chilling of the metal except at the top. Ingots yield 90 per cent. of sound steel.)

97. B. STOUGHTON : "The Making of Sound Steel Ingots." *Jnl. of the Franklin Inst.*, 1914, vol. clxxvii. p. 65; Abstr., *Jnl. I. & S. Inst.*, 1914, No. I. p. 681.

(Advantages of using ferro-titanium as deoxidiser.)

98. C. CANARIS : "New Processes for Obtaining Sound Steel Ingots." *Stahl und Eisen*, 1913, vol. xxxiii. p. 1890; Abstr., *Jnl. I. & S. Inst.*, 1914, No. I. p. 682.

(Various recently tried methods for producing sound ingots are discussed. Gathmann's and the thermit method give best results.)

99. J. O. ARNOLD and G. R. BOLSOVER : "The Forms in which Sulphides may Exist in Steel Ingots." *Jnl. I. & S. Inst.*, 1914, No. I. p. 396.

(Steel casts were treated so as to obtain ingots containing sulphides of iron and of manganese. Micrographs show the nature of these and the form in which they occur in the steel. The conclusions point to the probable existence in commercial steels of ferrite and sulphide of manganese, which has a very high freezing point. Aluminium plays some part in forming this eutectic.)

100. G. RÖHL : "The Constitution of the Sulphide Enclosures in Iron and Steel, and the Desulphurisation Process." *I. & S. Inst.: Carnegie Scholarship Memoirs*, 1912, vol. iv. p. 28.

(Reactions for distinguishing between iron sulphide and manganese sulphide and an examination of the system FeS–MnS. Necessity for desulphurisation with manganese, and the chemical reactions which produce the less harmful iron-manganese-sulphur compounds.)

101. L. BARADUC-MULLER : "The Gases Occluded in Liquid Steel." *I. & S. Inst.: Carnegie Scholarship Memoirs*, 1914, vol. vi. p. 216.

(Gases were extracted from liquid basic Bessemer steel under vacuum. From ½-ton ingots the volume of gas extracted ranged from 1160 to 1895 litres for each ingot. The gases from one ingot were in the following

proportion: $CO_2 = 42 \cdot 2$ litres; $O = 10 \cdot 6$; $CO = 352 \cdot 2$; $H = 604 \cdot 3$; Methane $= 2 \cdot 4$; and $N = 147 \cdot 7$ litres.)

102. J. A. Pickard and F. M. Potter: "The Oxygen Content of Open-Hearth Steel." *Jnl. I. & S. Inst.*, 1914, No. II. p. 181.

(No relation could be discovered between the oxygen and carbon content. All kinds of open-hearth steel can be made practically free from oxygen (not more than 0·010 per cent.). Acid open-hearth steel with carbon up to 1 per cent. contained oxygen = 0·011. Over 1 per cent. carbon the oxygen = 0·007. Basic steel showed oxygen = 0·021 for low-carbon steel and 0·011 for high-carbon steel.)

103. M. H. Wickhorst: "Aluminium in Rail Steel." *Iron Age*, 1914, vol. xciii. p. 1073; Abstr., *Jnl. I. & S. Inst.*, 1914, No. II. p. 373.

(Effect of aluminium in reducing segregation in acid Bessemer steel.)

104. Sir R. A. Hadfield and G. K. Burgess: "Sound Steel Ingots and Rails." *Jnl. I. & S. Inst.*, 1915, No. I. p. 40.

(Nine ingots, made by the converter process, were examined; weight, 2½ to 3 tons. The steel was ordinary rail steel. The split ingots showed the advantage of casting large end up and of feeding by the Hadfield process. Analyses and micrographs are given.)

105. G. K. Burgess and Sir R. A. Hadfield: "Sound Steel Ingots and Rails." *Trans. American Inst. of Mining Engineers*, 1915, vol. li. p. 862.

(This paper describes the work reported in the previous paper by same authors. *See* No. 104.)

106. J. O. Arnold and G. R. Bolsover: "Supplementary Notes on the Forms in which Sulphides may Exist in Steel Ingots." *Jnl. I. & S. Inst.*, 1915, No. I. p. 271.

(Beneficial influence of aluminium in preventing segregation. Micrographs show areas of eutectic structure of a decomposed solution or compound, the composition of which cannot readily be determined, but there are indications of the presence of roughly 12 per cent. MnS, corresponding to the formula $12\,Fe + MnS$.)

107. C. F. Williams: "Ingot Mould of Improved Design." *Iron Trade Review*, 1914, vol. lv. p. 765; Abstr., *Jnl. I. & S. Inst.*, 1915, No. I. p. 575.

(The Bradford ingot mould is described. It has an annular chamber at top in which charcoal or other fuel is burned after teeming the ingot. Loam is first thrown on the top of the liquid metal.)

108. G. F. Comstock: "Titanium Nitride in Steel." *Metallurgical and Chemical Engineering*, 1914, vol. xii. p. 577; Abstr., *Jnl. I. & S. Inst.*, 1915, No. I. p. 608.

(Minute hard non-metallic spots are often encountered in rails treated with ferro-carbon-titanium, the spots being evenly scattered and never segregated. Examination leads to the conclusion that the substance is titanium nitride. It is distinguishable by its pink colour.)

109. G. F. Comstock: "Titanium and its Effect on Steel." *Jnl. of the Soc. of Chemical Industry*, 1915, vol. xxxiv. p. 55; Abstr., *Jnl. I. & S. Inst.*, 1915, No. I. p. 606.

(Influence of titanium in preventing segregation. Results of tests are given, showing the improvement in the tensile properties of titanium-treated rails.)

110. F. GIOLITTI and G. TAVANTI: "Solubility of Slag Inclusions." *Annali di Chimica Applicata*, 1914, vol. ii. p. 360; Abstr., *Jnl. I. & S. Inst.*, 1915, No. I. p. 618.

(Acid and basic steels were suddenly cooled and slowly cooled from the liquid state, and annealed, but it was found that the slag inclusions were not appreciably modified by the different treatments. It is concluded that slag cannot be dissolved by molten steel.)

111. G. CHARPY: "Piping in Steel Ingots." *Génie Civil*, 1915, vol. lxvii. p. 7; Abstr., *Jnl. I. & S. Inst.*, 1915, No. II. p. 285.

(Discussion of various methods for improving soundness of ingots. The absurdity of specifications, which require a fixed proportion of discard, no matter how the ingot may have been cast or treated, is emphasised.)

112. E. F. KENNEY: "General Principles of the Control of Piping and Segregation of Steel Ingots." (Discussion.) *Year-Book of American Iron and Steel Inst.*, 1915, p. 464; Abstr., *Jnl. I. & S. Inst.*, 1915, No. II. p. 285.

(A special design of feeding-head is described.)

113. E. GATHMANN: "Methods of Preventing Piping in Steel Ingots." *Metallurgical and Chemical Engineering*, 1915, vol. xiii. p. 656; Abstr., *Jnl. I. & S. Inst.*, 1915, No. II. p. 285.

(Describes his form of ingot mould and results of its use. *See* No. 96.)

114. F. A. J. FITZGERALD: "Has Titanium any Influence on the Properties of Steel?" *Metallurgical and Chemical Engineering*, 1915, vol. xiii. p. 28; Abstr., *Jnl. I. & S. Inst.*, 1915, No. II. p. 312.

(Results are compared on 78 heats of rail steel without titanium, and 77 heats in which titanium was used. There is no doubt as to beneficial effect of titanium.)

115. W. H. HATFIELD: "Phosphorus in Iron and Steel." *Jnl. I. & S. Inst.*, 1915, No. II. p. 122.

(The distribution and condition of phosphide in steels is still open to careful consideration, and it is suggested that local high phosphorus is associated with areas richer in pearlite rather than with ferrite.)

116. R. H. IRONS: "Bottom Plates for Pouring Ingots." *Iron Age*, 1915, vol. xcvi. p. 1221; Abstr., *Jnl. I. & S. Inst.*, 1916, No. I. p. 349.

(An improved form of bottom plate for bottom pouring, so designed that the moulds are fed by runners of equal length and the same number of turns. This ensures uniform filling.)

117. H. M. HOWE: "General Principles of the Control of Piping and Segregation in Steel Ingots." *Year-Book of American Iron and Steel Inst.*, 1915, p. 446; Abstr., *Jnl. I. & S. Inst.*, 1916, No. I. p. 349.

(Discusses the usual means for reducing piping and segregation. The commonest method is to limit the killing of the steel so that it will evolve gas rather late during solidification, causing deep-seated blowholes which will weld more easily.)

118. R. W. HUNT: "Segregation in Ladle Test Ingots." *Bulletin of American Railway Engineering Association*, 1915, vol. xvii. p. 27; Abstr., *Jnl. I. & S. Inst.*, 1916, No. I. p. 350.

(Recommends standard shape and size for ladle test ingots, and that aluminium should be added, preferably in the dipper, to ensure soundness.)

119. F. Giolitti and S. Zublena: "Behaviour of Slag Inclusions in Acid Steel." *International Jnl. for Metallography*, 1914, vol. vii. p. 35; Abstr., *Jnl. I. & S. Inst.*, 1916, No. I. p. 350.

(Examination of an acid open-hearth steel ingot with 0·38 per cent. carbon and 2·02 per cent. nitrogen. The sound parts were examined, and grey sulphide enclosures in the central part of the ferrite masses, completely separated from the pearlite, were found.)

120. G. F. Comstock: "Alumina in Steel." *Metallurgical and Chemical Engineering*, 1915, vol. xiii. p. 891; Abstr., *Jnl. I. & S. Inst.*, 1916, No. I. p. 350.

(Photomicrographs of alumina inclusions, and discussion of these and how they are differentiated from silicate inclusions.)

121. J. O. Arnold: "The Cause and Effect of 'Ghost Lines' in Large Steel Forgings." *Proc. Inst. of Mechanical Engineers*, 1915, No. II. p. 653; Abstr., *Jnl. I. & S. Inst.*, 1916, No. I. p. 351.

(Investigation of nature of ghost lines in a forging from a 40-ton ingot. Ghosts are stated to be compound and variable segregates of carbon, sulphur, phosphorus, and nickel. Analyses show composition of ghosts compared with that of the sound steel.)

122. H. Le Chatelier and J. Lemoine: "Heterogeneity of Steel; Utility of the Cupric Chloride Reagent." *Revue de Métallurgie*, 1915, vol. xii. p. 649; Abstr., *Jnl. I. & S. Inst.*, 1916, No. I. p. 387.

(Use of cupric chloride reagent for detecting distribution of phosphorus.)

123. D. K. Tschernoff: "Works of D. K. Tschernoff." Republished by the Russian Technical Society, 1915. *See* French translation in *Revue de Métallurgie*, 1915, vol. xii. pp. 840–851.

(This is a reprint of Tschernoff's original paper published by the Imperial Russian Technical Society in 1879. He dealt with defects in steel castings, such as piping, blowholes, and segregation. His description of the crystallisation of a steel ingot has become classic.)

124. R. C. Woodward: "The Manufacture of Large Forging Ingots." *Iron Age*, 1916, vol. xcvii. p. 1138; Abstr., *Jnl. I. & S. Inst.*, 1916, No. II. p. 433.

(Describes the manufacture of large forging ingots from 4 to 25 tons, and precautions for avoiding segregation. The ingots were top-poured into corrugated round moulds.)

125. W. D. Bradford: "Commercial Production of Sound Ingots." *Iron Age*, 1915, vol. xcvi. p. 1464; Abstr., *Jnl. I. & S. Inst.*, 1916, No. II. p. 433.

(The Bradford mould has the usual taper, but the walls widen from about 16 inches from the top, and contain a chamber surrounding the head of the ingot in which charcoal is placed to keep the top molten. The walls of the mould are much thicker in the lower part than in the upper portion.)

126. P. Goerens and J. Paquet: "A New Method for Determination of Gases in Steel." *Ferrum*, 1915, vol. xii. pp. 57, 73; Abstr., *Jnl. I. & S. Inst.*, 1916, No. II. p. 433.

(An investigation of the amount of gas to be found in different kinds of steel. Basic Bessemer steel, at the end of the operation and before deoxidation, contains very little gas, but open-hearth basic, before deoxidation, contains much gas, probably because the nitrogen blowing through the converter metal carries away CO with it.)

127. P. GOERENS and L. COLLART: "Distribution of Gases in Steel Ingots." *Ferrum*, 1916, vol. xiii. p. 145; Abstr., *Jnl. I. & S. Inst.*, 1916, No. II. p. 434.

(A continuation of the investigation of the distribution of gas in steel ingots. The proportion of gas in an open-hearth ingot is 6·6 cubic centimetres per cubic centimetre of metal, and in the basic Bessemer ingot 8 cubic centimetres per cubic centimetre of metal. The gases tend to segregate more towards the centre than at the sides.)

128. A. SAUVEUR: "An Investigation dealing with the Occurrence of Alumina Inclusions in Steel." *Metallurgical and Chemical Engineering*, 1916, vol. xv. p. 149; Abstr., *Jnl. I. & S. Inst.*, 1916, No. II. p. 434.

(The detection of alumina inclusions in steel, and how they may be distinguished from other inclusions.)

129. J. A. PICKARD: "The Oxygen Content of Iron and Steel, and its Effect on their Properties." *I. & S. Inst.: Carnegie Scholarship Memoirs*, 1916, vol. vii. p. 68.

(A continuation of the author's previous work. (*See* No. 102.) The materials examined were acid and basic Bessemer steel, crucible steel, wrought iron, and American ingot iron. The general conclusion is that oxygen in steel in excess of 0·01 per cent. tends to produce brittleness under shock.)

130. J. W. DONALDSON: "Gases Occluded in Alloy Steel." *I. & S. Inst.: Carnegie Scholarship Memoirs*, 1916, vol. vii. p. 41.

(The volume of gas in alloy steel diminishes according as the special element is nickel, silicon, chromium, or manganese. The nature of the gases is similar to those of ordinary steel, except that silicon and manganese decrease the amount of CO_2. Chromium tends to increase the amount of nitrogen.)

131. H. M. BOYLSTON: "Relative Merits of Various Agents for the Deoxidation of Steel." *I. & S. Inst.: Carnegie Scholarship Memoirs*, 1916, vol. vii. pp. 102, 133.

(The effect of the following deoxidisers was studied: ferro-manganese, ferro-silicon, ferro-carbon-titanium, carbon-free ferro-titanium, and aluminium. Aluminium gave the densest ingots in general, but the relative order of the deoxidisers as regards their influence on the soundness of steel and its mechanical properties varied considerably. A table is given showing the order in which they rank.)

132. A. W. and H. BREARLEY: "Some Properties of Ingots." *Jnl. I. & S. Inst.*, 1916, No. II. p. 137.

(The phenomena of freezing and crystallisation of steel ingots are studied, and some illustrations are given by means of wax ingots. The advantages of casting wide end up are shown.)

133. J. N. KILBY: "Steel Ingot Defects." *Jnl. I. & S. Inst.*, 1916, No. II. p. 193; 1917, No. I. p. 69.

(The effect of tun-dish pouring on top-poured steel. Practical experiments in top pouring and bottom pouring are described. The second paper describes the defects in ingots due to faulty working of the charge and methods of teeming.)

134. G. K. Burgess : " Temperature Measurements in Bessemer and Open-Hearth Practice." *Washington Bureau of Standards, Technologic Paper No.* 91, 1917 ; *Trans. American Inst. of Mining Engineers*, 1916–17, vol. lvi. p. 432 ; Abstr., *Jnl. I. & S. Inst.*, 1917, No. I. p. 364.

(Application of pyrometric methods for determining the temperatures of streams of steel in teeming, with tables of temperatures of metal during pouring.)

135. J. R. Cain and H. S. Rawdon : " Standardisation of Ladle-Test Ingots." *Proc. of American Soc. for Testing Materials*, 1916, vol. xvi. p. 129 ; Abstr., *Jnl. I. & S. Inst.*, 1917, No. I. p. 371.

(Out of 25 test ingots, 15 were found to be non-homogeneous as to carbon, 9 as to sulphur, and 9 as to phosphorus. There is a tendency to deoxidation in the regions surrounding the blowholes whose walls are covered with oxide scale.)

136. A. McCance : " Non-Metallic Segregation in Steel." *Jnl. of West of Scotland I. & S. Inst.*, 1916–17, vol. xxiv. p. 55 ; Abstr., *Jnl. I. & S. Inst.*, 1917, No. I. p. 394.

(Investigation of the segregation of non-metallic impurities in steel. Examination of nature, composition, and distribution of inclusions.)

137. F. Bondolfi : " A Chapter on Applied Metallurgy : Liquation." *Metallurgia Italiana*, 1916, vol. viii. p. 165 ; Abstr., *Jnl. I. & S. Inst.*, 1917, No. I. p. 395.

(General discussion of inclusions, ghost lines, and segregation.)

138. G. F. Comstock : " A Method for Distinguishing Sulphides from Oxides in the Metallography of Steel." *Trans. American Inst. of Mining Engineers*, 1916–17, vol. lvi. p. 553 ; Abstr., *Jnl. I. & S. Inst.*, 1917, No. I. p. 395.

(Iron oxide inclusions can assume the same light grey appearance as manganese sulphide. An easy test to distinguish between them is to apply boiling alkaline sodium picrate, which will attack and blacken the sulphide inclusions, leaving the oxides unchanged.)

139. H. M. Howe : " On the Formation of Columnar and of Free Crystals during Solidification." *Metallurgical and Chemical Engineering*, 1916, vol. xv. p. 623 ; Abstr., *Jnl. I. & S. Inst.*, 1917, No. I. p. 412.

(Phenomena of crystallisation of steel ingots during freezing. Effect of chill moulds.)

140. Anon. : " Improvements in Ingot Moulds." *Iron & Coal Trades Review*, 1917, vol. xcv. p. 198 ; Abstr., *Jnl. I. & S. Inst.*, 1917, No. II. p. 414.

(An improved construction of heavy ingot mould is described. Quick cooling is promoted by circulating a cooling medium within the walls and bottom plate.)

141. G. W. Dress : " Defects in Finished Rolled Steel." *Iron Age*, 1917, vol. xcix. p. 1548 ; Abstr., *Jnl. I. & S. Inst.*, 1917, No. II. p. 439.

(Rough and pitted surfaces on finished rolled steel are due to slag inclusions. The primary cause of this defect is faulty reheating. If overheated, running slag will enter pinholes and so into gas cells near the surface, and such slag particles cannot be eliminated.)

142. B. Talbot: "Production of Sound Steel by Lateral Compression of the Top Portion of the Ingot." *Jnl. I. & S. Inst.*, 1918, No. I. p. 221.

(Ingots are cast in moulds with a refractory-lined top. The design is shown. The refractory lining consists of slag-poured liquid into the widened head of the mould round a cast-iron core, which is removed when the slag has set. A hydraulic compression press is described in which the top part of the ingot is squeezed while liquid in the centre. Details of the operations are described. Solid ingots are obtained with a small amount of segregation in the crop-piece of not more than 2½ per cent. of the ingot.)

143. A. McCance: "Non-Metallic Inclusions: their Constitution and Occurrence in Steel." *Jnl. I. & S. Inst.*, 1918, No. I. p. 239.

(A further and more detailed investigation of the nature, composition, and distribution of inclusions. *See* No. 136.)

144. J. E. Stead: "Note on Inclusions and Ferrite Lines." *Jnl. I. & S. Inst.*, 1918, No. I. p. 287.

(Non-metallic inclusions and empty cavities in steel do not lead ferrite to crystallise around them. Phosphorus—almost always associated with inclusions—leads to formation of ghost lines.)

145. J. N. Kilby: "Defects in Steel Ingots." *Jnl. I. & S. Inst.*, 1918, No. I. p. 365.

(Influence of methods of working and teeming on the soundness of ingots and formation of inclusions.)

146. Cosmo Johns: "Origin of the Oxygen Compounds found in Steel." *Jnl. of Soc. of Chemical Industry*, 1918, vol. xxxvii. p. 145R; Abstr., *Jnl. I. & S. Inst.*, 1918, No. I. p. 517.

(Origin of oxygen compounds in steel. The more oxidising the conditions under which the steel was made the larger will be the total amount of oxygen compounds, solid or gaseous.)

147. G. Charpy and S. Bonnerot: "Heterogeneity of Steels." *Comptes Rendus*, 1917, vol. clxv. p. 536; Abstr., *Jnl. I. & S. Inst.*, 1918, No. I. p. 540.

(Modified cupriferous reagent of Le Chatelier and Lemoine reveals relative dimensions of laminations in rolled material, but gives no precise clue to degree of heterogeneity.)

148. J. E. Fletcher: "The Cooling of Steel in Ingot and other Forms." *Jnl. I. & S. Inst.*, 1918, No. II. p. 231.

(Cooling and crystallisation phenomena in steel ingots. Influence of form of mould and cooling conditions on piping, &c.)

149. F. C. Perkins: "Production of Sound Steel." *Canadian Machinery*, 1918, vol. xix. p. 647; Abstr., *Jnl. I. & S. Inst.*, 1918, No. II. p. 477.

(Describes results of casting ingots by the Gathmann method. The crop is approximately 5 per cent.)

150. A. M. Portevin and V. Bernard: "The Macrostructure of Steel." *Revue de Métallurgie*, 1918, vol. xv. p. 273; Abstr., *Jnl. I. & S. Inst.*, 1918, No. II. p. 483.

(The use of the Stead-Le Chatelier reagent in revealing the macrostructure of steel is described.)

151. H. Le Chatelier and E. L. Dupuy: "On the Heterogeneity of Steel." *Revue de Métallurgie*, 1918, vol. xv. p. 127.

(The efficiency of the Stead-Le Chatelier reagent in detecting heterogeneity of steel depends largely on exact amount of hydrochloric acid present.)

152. B. Yaneske: "Deoxidation and the Influence of Lime on Equilibrium in the Acid Open-Hearth Furnace." *Jnl. I. & S. Inst.*, 1919, No. I. p. 255.

(The majority of non-metallic inclusions in acid steel products consist of a mixture of silicates of iron and manganese (often with manganese sulphides) in solution. These silicates are chiefly formed by the addition of the deoxidisers silicon and manganese to a steel containing an appreciable quantity of dissolved oxygen as FeO and CO. The bath should therefore be free of oxides before adding the deoxidising alloys instead of relying on the addition of the alloys to effect deoxidation.)

153. J. C. W. Humfrey: "Macro-Etching and Macro-Printing." *Jnl. I. & S. Inst.*, 1919, No. I. p. 273.

(Causes of minor and major segregation. Methods for revealing macro-structure are described; precautions to be taken in sulphur printing; macro-etching solutions. The author's etching solution produces the delicacy of the structure and can be applied to surfaces with an emery-paper finish only, and any number of full-sized replicas can be obtained by printing. The solution is prepared by addition of hydrochloric acid to Heyn's reagent, the composition being stated. Interpretation of the etchings and examples of macro-etchings full size.)

154. A. L. Feild: "The Deoxidation of Steel by Ferro-Manganese." *Jnl. of Industrial and Engineering Chemistry*, 1919, vol. xi. p. 242; Abstr., *Jnl. I. & S. Inst.*, 1919, No. I. p. 662.

(The true function of ferro-manganese, ferro-silicon, and other deoxidisers is imperfectly understood. Samples of over-oxidised steel and of the same metal to which FeMn and FeSi have been added have been found to have the same oxygen content.)

155. W. L. Booth: "Making Sand-Cast Forging Ingots." *Iron Age*, 1918, vol. cii. p. 1139; Abstr., *Jnl. I. & S. Inst.*, 1919, No. I. p. 669.

(Describes casting of ingots up to 18 tons in sand moulds. Heat is not abstracted rapidly and ingot cools uniformly. Such ingots are said to be remarkably free from pipe.)

156. J. E. Fletcher: "Mechanical Methods used for the Production of Solid Steel Ingots." *Proc. of Staffordshire I. & S. Inst.*, 1918–19, vol. xxxiv. p. 55; Abstr., *Jnl. I. & S. Inst.*, 1919, No. I. p. 669.

(Describes the Harmet, Illingworth, Robinson and Rodger, and Talbot methods for production of sound ingots, and discusses influence of mass heating and cooling on crystalline structure.)

157. G. F. Comstock: "Metallographic Investigation of Transverse-Fissure Rails, with Special Reference to High-Phosphorus Streaks." *Trans. American Inst. of Mining Engineers*, 1918–19, vol. lxii. p. 703; Abstr., *Jnl. I. & S. Inst.*, 1919, No. I. p. 687.

(A connection is traced between transverse fissures in rails and high-phosphorus streaks. Rails rolled from reheated blooms are much less apt to contain such streaks than direct rolled rails.)

158. "Occlusion of Gases in Metals." General discussion before the Faraday Society. (Contributions by T. Baker, C. Johns, H. A. Kent, J. W. McBain, and A. W. Porter.) *Proc. of Faraday Society*, 1918–19; Abstr., *Jnl. I. & S. Inst.*, 1919, No. I. p. 689.

159. K. Harnecker and E. Rassow: "On the Use of Oberhoffer's Etching Reagent for Distinguishing Enriched Phosphorus Areas in Iron and Steel." *Stahl und Eisen*, 1918, vol. xxxviii. p. 1079; Abstr., *Jnl. I. & S. Inst.*, 1919, No. I. p. 690.

(Photomicrographs of specimens etched with Oberhoffer's modification of Stead's reagent for detection of phosphorus segregation.)

160. H. Le Chatelier and B. Bogitch: "Heterogeneity in Steel." *Comptes Rendus*, 1918, vol. clxvii. p. 472; Abstr., *Jnl. I. & S. Inst.*, 1919, No. I. p. 690.

(The macrostructure developed by etching with Stead's copper reagent has been ascribed to phosphorus segregations. The same structure can be developed in phosphorus-free steels, and it is suggested that oxygen remaining in solution as FeO is the real cause.)

161. F. Giolitti: "Observations on Flaky and Woody Steel." *Chemical and Metallurgical Engineering*, 1919, vol. xx. p. 271; Abstr., *Jnl. I. & S. Inst.*, 1919, No. I. p. 692.

(Discussion of occurrence and nature of flaky fracture in steel.)

162. C. Y. Clayton, F. B. Foley, and F. B. Laney: "Flaky and Woody Fractures in Nickel Steel Gun Forgings." *Trans. American Inst. of Mining Engineers*, 1918–19, vol. lxii. p. 211; Abstr., *Jnl. I. & S. Inst.*, 1919, No. I. p. 692.

(Discussion of flaky and fibrous fractures and their causes.)

163. H. S. Rawdon: "Microstructural Features of Flaky Steel." *Trans. American Inst. of Mining Engineers*, 1918–19, vol. lxii. p. 246; Abstr., *Jnl. I. & S. Inst.*, 1919, No. I. p. 693.

(Description of flakes in steel, with photomicrographs.)

164. H. D. Hibbard: "Present Knowledge concerning Non-Metallic Impurities of Steel (Sonims)." *Year-Book of American Iron and Steel Inst.*, 1919, p. 93; *Iron Age*, 1919, vol. ciii. p. 1427; Abstr., *Jnl. I. & S. Inst.*, 1919, No. II. p. 522.

(Composition, distribution, and mode of occurrence of inclusions in steel.)

165. H. Styri: "Observations on so-called 'Flakes' in Steel." *Chemical and Metallurgical Engineering*, 1919, vol. xx. pp. 342, 478; Abstr., *Jnl. I. & S. Inst.*, 1919, No. II. p. 523.

(Study of the occurrence of flakes in steel. Chief cause of flakes is ascribed to slag inclusions, but they may be caused by cracks, blowholes, or segregation. Elimination in the process of manufacture of the steel is recommended.)

166. E. E. Thum: "Flakes in Alloy Steel." *Chemical and Metallurgical Engineering*, 1919, vol. xxi. p. 145; Abstr., *Jnl. I. & S. Inst.*, 1919, No. II. p. 523.

(Careful furnace practice and subsequent heat treatment are the only ways to eliminate flakes. Gives review of recent literature on subject.)

167. H. Le Chatelier and B. Bogitch : "Macrography of Steels ; Corrosion Test." *Revue de Métallurgie*, 1919, vol. xvi. p. 129 ; Abstr., *Jnl. I. & S. Inst.*, 1919, No. II. p. 527.

(The macrographic structure is due to oxygen, and, in the case of annealed or slowly cooled steel, it is oxygen that is responsible for the structure.)

168. J. J. Cohade : "The Woody Structures of Fractures of Transverse Test-Pieces taken from Certain Special Steels." *Jnl. I. & S. Inst.*, 1919, No. II. p. 187.

(Origin of flakes causing a woody fracture. Composition exercises an important influence on results of transverse tests showing a woody fracture. The percentage of carbon is the most important factor. Carbon should not exceed 0·30 per cent. in gun steels.)

169. A. M. Portevin : "Defective Fractures in Tensile Test-Pieces during the Inspection of Gun Parts." *Jnl. I. & S. Inst.*, 1919, No. II. p. 203.

(Different types of flaky fracture are discussed. Fracture is caused by the existence of local defects due to an accumulation of sulphide inclusions lying parallel with the direction of forging.)

170. J. H. Andrew, J. N. Greenwood, and G. W. Green : "Nickel-Chrome Forgings." *Jnl. I. & S. Inst.*, 1919, No. II. p. 231.

(The authors investigated the processes and practice involved in the manufacture of large nickel-chrome forgings. Nineteen ingots in all were followed : five 45-ton, six 22-ton, and eight 11-ton. The 45-ton ingots were cast wide end up, the 22- and 11-ton narrow end up. The casting temperature ranged from 1300° to 1390° C., and the time of teeming for the 45-ton ingots was—minimum 20·5 seconds, maximum 26·5 seconds per ton ; for the 22-ton ingots it was — minimum 19·1 seconds, maximum 41 seconds per ton ; and for the 11-ton ingots it was—minimum 35·5 seconds, maximum 87 seconds per ton. The lower the casting temperature and the slower the teeming the better was the ingot. High temperature promotes growth of columnar crystals, which is dangerous in ingots possessing corners. Segregation in the 11-ton ingot was practically negligible, but the pipe extended nearly the whole length of the ingot. The 22-ton ingot showed secondary piping below the primary, and considerable segregation of carbon, phosphorus, sulphur, and chromium, and slight segregation of nickel. The 45-ton ingot showed localised segregation, and the pipe was confined to the head, the ingot being otherwise sound throughout.)

171. H. M. Howe and E. Groesbeck : "Prevention of Columnar Crystallisation by Rotation during Solidification." *Trans. American Inst. of Mining & Metallurgical Engineers*, 1918–19, vol. lxii. p. 341 ; Abstr., *Jnl. I. & S. Inst.*, 1919, No. II. p. 500.

(Experiments on the effect of rotation as a means of preventing columnar crystallisation in steel during solidification. The mechanism of solidification is explained. To differentiate more clearly the crystallisation phenomena in a metal mass, a mixture of zinc with 5 per cent. of type metal was poured into a rotating mould and into a stationary one. The stationary ingot showed marked columnar crystals, the rotated one only strong spiral markings on the outside.)

172. J. H. Whiteley: "The Distribution of Phosphorus in Steel between the Points Ac1 and Ac3." *Jnl. I. & S. Inst.*, 1920, No. I. p. 359.

(An investigation of the distribution of phosphorus in steel as influenced by heat treatment. Velocity of diffusion of phosphorus at different temperatures in ferrite and in γ-iron.)

173. H. D. Hibbard: "Effervescing Steel." *Trans. American Inst. of Mining & Metallurgical Engineers*, 1918–19, vol. lxii. p. 160; Abstr., *Jnl. I. & S. Inst.*, 1920, No. I. p. 716.

(Causes of blowholes and their distribution in the ingot. Effervescence in the mould appears to be thought desirable, as large volumes of gas are thereby evolved.)

174. F. E. Bash: "Electric, Open-Hearth, and Bessemer Steel Temperatures." *American Inst. of Mining & Metallurgical Engineers, Symposium on Pyrometry, New York*, 1920, p. 578; Abstr., *Jnl. I. & S. Inst.*, 1920, No. I. p. 719.

(Measurement of tapping temperatures, using a disappearing-filament type of optical pyrometer.)

175. P. Oberhoffer and A. Beuttel: "Measurement of Gases in Steel." *Stahl und Eisen*, 1919, vol. xxxix. p. 1584; Abstr., *Jnl. I. & S. Inst.*, 1920, No. I. p. 720.

(A new apparatus is devised for the rapid extraction and measurement of the gases in basic Bessemer and open-hearth steel before and after deoxidation.)

176. S. W. Williamson: "Casting of Steel Ingots." *Jnl. of West of Scotland I. & S. Inst.*, 1919–20, vol. xxvii. p. 94.

(The importance of rate of pouring and of design of ingot mould in producing sound steel are considered. The speed of pouring depends on the head of metal in the ladle, and alteration in the opening of the nozzle as pouring proceeds.)

177. E. Kothny: "Influence of Deoxidation and Time of Solidification on the Quality of Electric Nickel-Chrome Steel." *Stahl und Eisen*, 1920, vol. xl. p. 41; Abstr., *Jnl. I. & S. Inst.*, 1920, No. I. p. 724.

(Insufficient deoxidation results in granular structure, which lowers the quality of the metal.)

178. G. Charpy: "Microscopic Cavities in Steel Ingots." *Comptes Rendus*, 1920, vol. clxx. p. 306; Abstr., *Jnl. I. & S. Inst.*, 1920, No. I. p. 724.

(Minute cavities formed in steel during solidification can be removed by reheating to 1350° C. and submitting it while hot to slight longitudinal compression.)

179. A. W. Lorenz: "Fibrous Structure in High Carbon Steel." *Chemical and Metallurgical Engineering*, 1919, vol. xxi. p. 203; Abstr., *Jnl. I. & S. Inst.*, 1920, No. I. p. 724.

(The practice of washing ingot moulds with tar may at times be responsible for fibrous structure, as gas may work its way into the freezing metal. Graphite wash is free from this objection.)

180. E. G. Mahin : "Effect of Non-Metallic Inclusions upon the Properties of Iron and Steel." *Jnl. of Industrial and Engineering Chemistry*, 1919, vol. xi. p. 739; Abstr., *Jnl. I. & S. Inst.*, 1920, No. I. p. 725.

(The recurrence of ferrite streaks after repeated heat treatment which would break up any ordinary carbon segregation is due to phosphorus banding, which is little changed by ordinary treatment. Even after phosphorus distribution has been made uniform, repeated heating followed by slow cooling leaves inclusions surrounded by ferrite.)

181. M. C. Smith : "Aluminium Additions and Sulphur Segregations." *Iron Age*, 1920, vol. cv. p. 1426; Abstr., *Jnl. I. & S. Inst.*, 1920, No. II. p. 358.

(In adding aluminium, the best results are obtained by adding the aluminium gradually during pouring the ingot, rather than in a lump at the top.)

182. F. Giolitti : "Cracks in Ingots." *Chemical and Metallurgical Engineering*, 1920, vol. xxiii. p. 149; Abstr., *Jnl. I. & S. Inst.*, 1920, No. II. p. 363.

(Deep-seated cracks are due to generation of parasitic centres of crystallisation.)

183. H. Brearley : "Steel Billets for Drop Forgers." *Jnl. West of Scotland I. & S. Inst.*, 1920, vol. xxvii. p. 63.

(Discussion of formation of cracks, blowholes, piping, segregation, and non-metallic inclusions in steel ingots.)

184. L. Aitchison : "Zones of Weakness in Solidified Ingots." *Chemical and Metallurgical Engineering*, 1920, vol. xxiii. p. 280; Abstr., *Jnl. I. & S. Inst.*, 1920, No. II. p. 363.

(Crystallisation of ingots and position of zones of weakness.)

185. H. Brearley : "The Welding of Steel in Relation to the Occurrence of Pipe, Blowholes, and Segregates in Ingots." *Jnl. I. & S. Inst.*, 1921, No. I p. 27.

(Occurrence of hair-lines in ingots and the conditions under which these may be welded up. Methods of measuring the efficiency of a weld. If a certain degree of toughness is imparted to the metal, the welds will always pull apart under the nicked bar test.)

186. J. E. Stead : "Solid Solution of Oxygen in Iron." *Jnl. I. & S. Inst.*, 1921, No. I. p. 271.

(Experiments show that, when iron is heated in air or oxidising gases, the surface layers apparently absorb oxygen which passes into solid solution. When supersaturated, the oxide falls out of solution, forming separate globules of free oxide, which enlarge till they join and form continuous layers. Sulphur possible as SO_2 in the gases penetrates into the body of the crystals, forming sulphide of manganese.)

187. J. H. Whiteley : "Cupric Etching Effects produced by Phosphorus and Oxygen in Iron." *Jnl. I. & S. Inst.*, 1921, No. I. p. 278.

(By means of cupric reagents differences in phosphorus of less than 0·02 per cent. in adjacent parts of iron may be detected. An unequal distribution of oxygen which might be detected by cupric reagents could not be produced.)

188. E. Killing: "The Effective Use of Manganese in the Basic Open Hearth." *Stahl und Eisen*, 1920, vol. xl. p. 1545; Abstr., *Jnl. I. & S. Inst.*, 1921, No. I. p. 420.

(To secure the most effective use of manganese additions, the charge should be tapped at the moment of maximum reduction of manganese from the slag. The manganese addition should be kept low, not above 1·6 to 1·8 per cent. The bases should be added in such quantities as neither to exceed nor fall short of the capacity of the slag for absorption.)

189. J. R. Cain: "New Deoxidisers for Steel Manufacture." *Chemical and Metallurgical Engineering*, 1920, vol. xxiii. p. 879; Abstr., *Jnl. I. & S. Inst.*, 1921, No. I. p. 421.

(Report of Bureau of Standards giving results of an investigation of the function and action of deoxidisers. Seventy-three deoxidising alloys are shown to have melting points below the melting point of pure iron.)

190. G. Niemkof: "Reduction of the Pipe in Bottom-Poured Ingots." *Revue de Métallurgie*, 1920, vol. xvii. p. 842; Abstr., *Jnl. I. & S. Inst.*, 1921, No. I. p. 428.

(A mould of special design was used. The wall at the bottom was thick; at the middle part a hollow space was provided all round and filled with non-conducting material, the inner part at this point being kept thin. The top was refractory-lined.)

191. G. K. Burgess: "Steel Rails from Sink-Head and Ordinary Rail Ingots." *Chemical and Metallurgical Engineering*, 1920, vol. xxiii. pp. 921, 969, 1017; Abstr., *Jnl. I. & S. Inst.*, 1921, No. I. p. 428.

(Sink-head ingots of the Hadfield type give much more uniform metal than ordinary ingots. An exhaustive comparison is made of both kinds of ingots as to suitability for rail-rolling.)

192. E. Gathmann: "Casting and Moulding Steel Ingots." *Trans. American Inst. of Mining & Metallurgical Engineers*, 1920–22, vol. lxvii. p. 514.

193. A. B. Wilson: "Defects in Steel originating in the Ingot." *Chemical and Metallurgical Engineering*, 1920, vol. xxiii. pp. 1161, 1209.

194. E. Kothny: "Influence of Deoxidation and Period of Solidification on the Quality of Electric Nickel-Chrome Steel." *Stahl und Eisen*, 1920, vol. xl. p. 41.

195. E. Kothny: "Conditions for the Manufacture of Nickel-Chrome Steel for Aero Crankshafts." *Stahl und Eisen*, 1920, vol. xl. p. 677.

196. M. Matweieff: "Metallographic Methods for Studying the Nature of Non-Metallic Inclusions in Iron and Steel." *Revue de Métallurgie*, 1920, vol. xvii.; Abstr., *Jnl. I. & S. Inst.*, 1921, No. I. p. 429.

(For determining the constituents of inclusions, the best results were obtained by the use of 0·2 per cent. oxalic acid, which attacks sulphide inclusions but does not affect the polished surface of the specimens.)

197. A. A. Rackoff: "Improving Steel by New Pouring Method." *Iron Trade Review*, 1920, vol. lxvii. p. 1601; Abstr., *Jnl. I. & S. Inst.*, 1921, No. I. p. 429.

(Describes use of a ladle with a strainer which prevents solid particles from entering the mould.)

198. E. G. MAHIN and E. H. HARTWIG : "Inclusions and Ferrite Crystallisations in Iron and Steel." *Jnl. of Industrial and Engineering Chemistry*, 1920, vol. xii. p. 1090; Abstr., *Jnl. I. & S. Inst.*, 1921, No. I. p. 429.

(The solubility of inclusions and their influence in producing ferrite segregations are discussed.)

199. E. G. MAHIN and G. E. BREWER : "An Electrometric Method for Detecting Segregation of Dissolved Impurities in Steel." *Jnl. of Industrial and Engineering Chemistry*, 1920, vol. xii. p. 1095; Abstr., *Jnl. I. & S. Inst.*, 1921, No. I. p. 430.

200. R. C. WOODWARD : "A Proposed New Ingot Mould for Steel." *Iron Age*, 1921, vol. cvii. p. 262.

(Discussion of cracks in ingots and effect of heavy moulds, and of advantages of a thin steel mould with water-cooling.)

201. J. H. ANDREW : "Casting and Treatment of Steel." *Trans. of North-East Coast Inst. of Engineers and Shipbuilders*, 1920, vol. xxxvi. p. 355; Abstr., *Jnl. I. & S. Inst.*, 1921, No. I. p. 438.

(Describes three methods for obtaining fine structure in steel.)

202. J. H. ANDREW : "Defects in Steel and their Detection." *Jnl. of West of Scotland I. & S. Inst.*, 1920–21, vol. xxviii. p. 28; Abstr., *Jnl. I. & S. Inst.*, 1921, No. I. p. 460.

(Methods for detection of defects : micro-examination, macro-printing; the taking of recalescence curves, determination of dilatation, measurement of resistivity, and testing of magnetic properties.)

203. E. H. SCHULZ and J. GOEBEL : "Flaky Fracture in Steel." *Stahl und Eisen*, 1920, vol. xl. p. 1479; Abstr., *Jnl. I. & S. Inst.*, 1921, No. I. p. 460.

(Two kinds of flaky fracture may be distinguished: one due to flaws arising from piping, inclusions, blowholes, slag threads, and segregation; the other is not yet fully explained, but is apparently connected with internal stresses.)

204. J. W. DONALDSON : "Gases Occluded in Steel." *Trans. of Faraday Society*, 1920, vol. xv. Pt. III. p. 238; Abstr., *Jnl. I. & S. Inst.*, 1921, No. I. p. 463.

(A 3·37 per cent. nickel steel and three mild steels were examined. The occluded gases are of a nature similar to those of other carbon steels.)

205. H. S. RAWDON : "Macroscopic Examination of Metals." *Chemical and Metallurgical Engineering*, 1921, vol. ii. p. 385; Abstr., *Jnl. I. & S. Inst.*, 1921, No. I. p. 464.

(A list is given of the commonly used etching reagents for revealing macroscopic structure. Ammonium persulphate gives particularly good results.)

206. A. BRÜNINGHAUS and F. HEINRICH : "Piping and Segregation in Siliconised Ingots." *Stahl und Eisen*, 1921, vol. xli. p. 497.

(An investigation of the usual known methods for improving soundness of steel.)

207. "Macroscopic Examination of Metals." *Proc. of American Soc. for Testing Materials*, 1921, vol. xxi. p. 817; *Chemical and Metallurgical Engineering*, 1921, vol. xxv. p. 334.

(Routine methods for macroscopic examination of metals, and solutions to be used in etching.)

208. W. P. Barba and H. M. Howe: "Acid Open-Hearth Process for Manufacture of Gun Steels and Fine Steels." *Trans. American Inst. of Mining and Metallurgical Engineers*, 1920–22, vol. lxvii. p. 172; Abstr., *Jnl. I. & S. Inst.*, 1922, No. I. p. 579.

(Practice in working the charge and teeming. Factors governing the design of ingot moulds and recommendations as to the best and most suitable sizes and principal dimensions.)

209. F. Pacher: "Defects in Siliconised Open-Hearth Ingots." *Stahl und Eisen*, 1922, vol. xlii. pp. 485, 533, 573.

(Defects may be traced to conditions of tapping, the form of ingot mould and teeming. Precautions for avoiding defects are discussed, but most are of a nature that does not permit of complete remedy by any kind of treatment.)

210. W. J. Priestley: "Effect of Sulphides and Oxides in Ordnance Steel." *Trans. American Inst. of Mining and Metallurgical Engineers*, 1922, vol. lxvii. p. 317; Abstr., *Jnl. I. & S. Inst.*, 1922, No. II. p. 326.

(Description of manufacture of steel by duplex process (basic open-hearth furnace and finishing in basic electric furnace). The presence of sulphides and oxides does not greatly influence results of longitudinal tensile tests, but weakens the steel transversely. Tests on steels with varying sulphur and phosphorus percentages are recorded.)

211. P. Oberhoffer and E. Piwowarsky: "Determination of Gases in Steel." *Stahl und Eisen*, 1922, vol. xlii. p. 801; Abstr., *Jnl. I. & S. Inst.*, 1922, No. II. p. 332.

(Two methods for estimation of gases in steel are described, by treatment with bromide and treatment with sublimate. The quantities found were much lower than by extraction of the gases under vacuum. The bromide method gives trustworthy results for hydrogen, and neither method indicates nitrogen.)

212. "McConway Centrifugally Cast Steel." *Iron & Coal Trades Review*, 1922, vol. cv. p. 355; *Jnl. I. & S. Inst.*, 1922, No. II. p. 249.

213. J. B. Johnson and S. Daniels: "Study of some Failures in Aircraft Plane and Engine Parts." *Trans. American Soc. for Steel Treating*, 1922, vol. ii. p. 1167; Abstr., *Jnl. I. & S. Inst.*, 1922, No. II. p. 375.

(A review of several investigations by the Engineering Division of the Air Service of breakages under service conditions.)

214. P. Oberhoffer: "Influence of Rate of Solidification of the Double Carbide Steels." *Stahl und Eisen*, 1922, vol. xlii. p. 1240; Abstr., *Jnl. I. & S. Inst.*, 1922, No. II. p. 389.

215. T. P. Colclough: "The Constitution of Basic Slags: its Relation to Furnace Reactions." *Jnl. I. & S. Inst.*, 1923, No. I. p. 267.

(Reactions in basic open-hearth working.)

216. P. Oberhoffer and F. Koerber: "Behaviour of Manganese in the Basic Open-Hearth Process." *Stahl und Eisen*, 1923, vol. xliii. p. 329; Abstr., *Jnl. I. & S. Inst.*, 1923, No. I. p. 668.

(Reactions in basic open-hearth working.)

217. J. H. Whiteley: "The Dephosphorisation of Iron in the Basic Furnace." *Proc. Cleveland Inst. of Engineers*, 1922–23, No. II. p. 36; Abstr., *Jnl. I. & S. Inst.*, 1923, No. I. p. 669.

(The phosphate content of the slag and the phosphorus content of the metal may be increased or diminished simply by changing the concentration of silica.)

218. T. Swinden: "Notes on Production of Sound Steel." *Proc. of Staffordshire I. & S. Inst.*, 1922–23, vol. xxxvii. p. 80; Abstr., *Jnl. I. & S. Inst.*, 1923, No. I. p. 675.

(The action of manganese, silicon, and aluminium, whilst removing FeO and consequently CO, as a source of blowholes, increases the power of steel to retain hydrogen in a state of absorption.)

219. H. W. Gillett: "Application of Colloid Chemistry to Production of Clean Steel." *Trans. American Inst. of Mining and Metallurgical Engineers*, 1923, vol. lxix. p. 768; Abstr., *Jnl. I. & S. Inst.*, 1923, No. I. p. 675.

(Dirt or inclusions are present in molten steel as an emulsion or suspension of colloidal nature. Present methods tend to destroy such colloidal suspensions, and other methods are known to the colloid chemist, but too little is known of the fundamental properties of colloids in molten metal to allow of their direct application.)

220. O. A. Knight: "Defects in Steel Ingots and Castings." *Forging and Heat Treating*, 1923, vol. ix. p. 98.

(A general discussion of defects commonly found in ingots, and of methods for their elimination or reduction.)

221. E. G. Mahin and H. W. Botts: "Non-Metallic Inclusions and Ferrite Segregations in Steel." *Chemical and Metallurgical Engineering*, 1922, vol. xxvii. p. 980; Abstr., *Jnl. I. & S. Inst.*, 1923, No. I. p. 675.

(Inclusions are centres of contamination for the steel mass and are not due so much to any connection between dissolved gases and state of oxidation of the inclusion.)

222. T. H. Turner: "Ingot Corner Segregation in a Nickel-Chrome Steel." *Proc. of Staffordshire I. & S. Inst.*, 1922–23, vol. xxxviii. p. 17; Abstr., *Jnl. I. & S. Inst.*, 1923, No. I. p. 676.

(Planes of segregation found at places corresponding to the eight corners of the original ingot. Between the segregation areas the steel was normally sound. The segregations were chiefly manganese sulphides.)

223. O. Bauer: "Segregation of Phosphorus in Mild Steel." *Mitteilungen aus dem Materialprüfungsamt*, 1922, vol. xl. p. 71; Abstr., *Jnl. I. & S. Inst.*, 1923, No. I. p. 676.

(General discussion of segregations and means for their detection.)

224. F. Sommer and F. Rapatz: "A Study of the Woody Fractures and Formation of Flakes in Steel." *Stahl und Eisen*, 1922, vol. xlii. p. 1708; Abstr., *Jnl. I. & S. Inst.*, 1923, No. I. p. 716.

(A microscopic examination of pieces cut from a steel billet showed numerous minute hard non-metallic inclusions. Owing to their unyielding hardness they have an explosive effect on the surrounding steel when rolled or forged, and produce "hair-cracks." These inclusions are considered to consist of particles of slag, and the more frequent occurrence of hair-cracks in basic than in acid steel is thought to be due to the more flint-like character of basic slag, whereas acid slag particles are plastic. By careful deoxidation and teeming, the trouble can be avoided. Flakes are probably due to the effect of the residual products of deoxidation in causing ferrite to separate.)

225. F. Giolitti: "The Complex Action of Manganese and other so-called Deoxidising Agents used in the Manufacture of Steel." *Jnl. I. & S. Inst.*, 1923, No. II. p. 35.

(Conditions under which manganese will exercise its maximum purifying action.)

226. J. Descolas and E. Pretet: "Macrographic Investigation of the Cooling of Steel Ingots." *Revue de Métallurgie*, 1923, vol. xx. p. 597; Abstr., *Jnl. I. & S. Inst.*, 1923, No. II. p. 438.

(Macrographs of ingots cast in moulds with walls of different thickness and of an ingot cast in a mould half of iron and half of sand. After rolling, heating, and cooling, the original structure is rendered visible by macrographic etching.)

227. T. Berglund: "Studies of the Segregation Phenomena in a 0·20 per Cent. Carbon Acid Open-Hearth Ingot." *Jernkontorets Annaler*, 1923, vol. lxxviii. p. 149; Abstr., *Jnl. I. & S. Inst.*, 1923, No. II. p. 438.

(Exhaustive report on segregation in an acid open-hearth ingot.)

228. B. D. Saklatwalla: "Ingot Structure and Heat Treatment." *Iron Age*, 1923, vol. cxii. p. 815; Abstr., *Jnl. I. & S. Inst.*, 1923, No. II. p. 439.

(Effect of electro-magnetic treatment during solidification of an ingot. The different constituents will be differently affected by a magnetic field, and molecular vibratory disturbances may be set up, helping towards elimination of gases and non-metallic impurities. It does not appear that any experiments have been made.)

229. L. Jordan: "Gases in Metals." *Proc. American Soc. for Testing Materials*, 1923, vol. xxiii. Part II. p. 7; Abstr., *Jnl. I. & S. Inst.*, 1923, No. II. p. 439.

(A vacuum fusion method for determining oxygen and hydrogen is described, and results show a progressive decrease in gas content, according to quantity of deoxidisers added and stage of deoxidation.)

230. E. G. Mahin and G. B. Wilson: "Non-Metallic Inclusions in Hypereutectoid Steel." *Industrial and Engineering Chemistry*, 1923, vol. xv. p. 829; Abstr., *Jnl. I. & S. Inst.*, 1923, No. II. p. 468.

(Ordinary segregation of dissolved elements may be cured by heat treatment, but no treatment will remove effects of non-metallic inclusions.)

231. W. OERTEL and A. RICHTER : " Influence of Deoxidation on the Capacity for Hot-Working and Properties of a Nickel-Chrome Structural Steel." *Stahl und Eisen*, 1924, vol. xliv. p. 169 ; Abstr., *Jnl. I. & S. Inst.*, 1924, No. I. p. 564.

(Half-ton nickel-chrome ingots were prepared, and influence of teeming temperature, speed of teeming, heat conductivity of the mould, and period of soaking were studied.)

232. G. K. BURGESS and G. W. QUICK : " A Comparison of the Deoxidation Effects of Titanium and Silicon on the Properties of Rail Steel." *U.S. Bureau of Standards*, 1923, *Technologic Paper No.* 241 ; Abstr., *Jnl. I. & S. Inst.*, 1924, No. I. p. 568.

(The titanium-treated rails were less segregated, but any nitrogen remaining in the steel tends to combine with the titanium and forms minute orange and violet inclusions. As a whole, titanium treating does not improve the mechanical properties so much as would be expected from the decreased segregation.)

233. W. J. PRIESTLEY : " Effect on Steel of Variations in Rate of Cooling in Ingot Moulds." *Trans. American Inst. of Mining and Metallurgical Engineers*, 1924, vol. lxx. ; Abstr., *Jnl. I. & S. Inst.*, 1924, No. I. p. 569.

(Ingotism, segregation, and formation of dendrites bear definite relations to rate of cooling and solidification in the mould.)

234. E. GATHMANN : " Fundamentals Essential to Improved Quality of Steel Production." *Trans. American Soc. for Steel Treating*, 1924, vol. v. p. 158.

(A general discussion of present state of knowledge.)

235. C. BENEDICKS and V. LÖF : " A Rational Form of Ingot Mould for Steels Difficult to Roll." *Jernkontorets Annaler*, 1924, vol. lxxix. p. 178.

236. B. P. HAIGH : " Slag Inclusions in Relation to Fatigue." *Trans. of Faraday Soc.*, 1924 ; Abstr., *Jnl. I. & S. Inst.*, 1924, No. I. p. 594.

(Inclusions may influence fatigue in three ways: chemically, expansively, or elastically.)

237. A. SAUVEUR and V. N. KRIVOBOK : " Use of Sodium Picrate in Revealing Dendritic Segregation in Iron Alloys." *Trans. American Inst. of Mining and Metallurgical Engineers*, 1924, vol. lxx. p. 239 ; Abstr., *Jnl. I. & S. Inst.*, 1924, No. I. p. 616.

238. A. SAUVEUR : " Crystallisation of Iron and its Alloys." *Trans. American Soc. for Steel Treating*, 1923, vol. iv. pp. 12, 83 ; Abstr., *Jnl. I. & S. Inst.*, 1924, No. I. p. 618.

(Describes dendritic crystallisation of iron-carbon alloys and their further transformations.)

239. H. D. HIBBARD : " Partly Killed Simple Steels." *Iron Age*, 1924, vol. cxiv. pp. 565, 599, 631 ; Abstr., *Jnl. I. & S. Inst.*, 1924, No. II. p. 395.

(Partly killed steel is that which contains harmful blowholes. Killed steel contains no blowholes, and full effervescing steel only such as are practically harmless. Basic open-hearth ingots of 1 to 3 tons weight were investigated. The completeness with which steel not effervescing is killed depends on the treatment in the furnace during and after melting, on the casting temperature, and on the additions at the end. Killed steel should always be cast in moulds large end up.)

240. VIVANTI: "The Use of Titanium in the Manufacture of Steel." *Metallurgia Italiana*, 1924, vol. xvi. p. 5; Abstr., *Jnl. I. & S. Inst.*, 1924, No. II. p. 396.

(Titanium is employed in two forms: ferro-carbon-titanium with titanium = 15·75 per cent.; carbon = 7·5; silicon = 1·41; and carbon-free ferro-titanium with 25 per cent. titanium and 5 per cent. aluminium. Comparative tests of rails and plates treated with titanium and of others treated with aluminium are given, and the titanium-treated products gave the better results.)

241. K. G. TROUBINE: "A Hypothesis Relative to the Origin of Surface Blow-holes in Steel Ingots." *Revue de Métallurgie*, 1924, vol. xxi. p. 288; Abstr., *Jnl. I. & S. Inst.*, 1924, No. II. p. 399.

(The formation of surface blowholes is not yet satisfactorily explained. In wild steel they form by the escape of occluded gases during solidification, and the extent to which they occur is related to the silicon percentage. They are larger in proportion as the ingot increases in size. In quiet steel, surface blowholes may be due to air entrained in the stream of metal. The thickness of wall of the ingot mould has considerable influence on the depth of surface blowholes.)

242. W. OERTEL and L. A. RICHTER: "The Influence of Deoxidation on the Hot-Working and Properties of a Nickel-Chromium Structural Steel." *Glockenstahlwerke, Remscheid. Report No.* 3; Abstr., *Jnl. I. & S. Inst.*, 1924, No. II. p. 400.

(In nickel-chrome steel the influence of teeming temperature, teeming speed, heat conductivity of the mould, rolling temperature, and length of soaking period were studied. The quality of the steel really depends on the careful deoxidation of the bath and elimination of gases. Ferro-manganese properly used is the best deoxidiser. The influence of all the factors is determined by tensile and impact tests.)

243. W. OERTEL and L. A. RICHTER: "Continuation of same Investigation." *Report No.* 4; Abstr., *Jnl. I. & S. Inst.*, 1924, No. II. p. 428.

(In the routine testing of nickel-chrome steel, containing 4·5 per cent. nickel and 1 to 1·5 per cent. chromium, considerable discrepancies were noted, especially in the notch toughness of specimens taken across the grain of the forging. As the cross-section of the bars and the heat treatment were the same in all cases, it was supposed that the size of the original ingot and the varying degree of forging in the hot state must have some influence on the nature of the finished forging. The results of experiments confirmed that the specific work of rupture is very greatly affected by the degree of deformation in the hot state. The more the piece is drawn out under the hammer, the higher is the specific work of rupture in longitudinal bars, but that of bars cut transversely is lowered. The spreading of a forging under the hammer, however, produces just the opposite effect. The influence of the ingot size diminishes according as the cross-section is reduced by forging. The changes in notch toughness are attributable to the development and changes in the primary fibrous structure due to deformation in the hot state.)

244. V. O. HOMERBERG: "The Macroscopic Examination of Steel." *Trans. American Soc. for Steel Treating*, 1924, vol. vi. p. 294; Abstr., *Jnl. I. & S. Inst.*, 1924, No. II. p. 449.

(The preparation of specimens for macroscopic examination, and the formulæ for the reagents. Macrographs illustrate results obtained with different reagents.)

245. J. Durand : "New Macrographic Process for the Examination of Metals." *Génie Civil*, 1924, vol. lxxxv. p. 131 ; Abstr., *Jnl. I. & S. Inst.*, 1924, No. II. p. 449.

(The use of photographic plates or films coated with silver bromide is recommended instead of sulphur prints by the Baumann method. Comparison of sulphur content of two steels can, however, only be made if the manganese content of both is about the same.)

246. H. Schottsky : "Detection of Sulphur and Phosphorus by Metallographic Methods." *Kruppsche Monatshefte*, 1924, vol. v. p. 93 ; Abstr., *Jnl. I. & S. Inst.*, 1924, No. II. p. 449.

(Sulphur prints taken across the grain blacken more strongly than when taken on a longitudinal section, although analysis may show sulphur to be evenly distributed. Degree of discoloration does not depend on amount of sulphur actually present but on the form and number of sulphide inclusions. On a cross-section these appear as small spots close together, but on a longitudinal one as short threads comparatively wider apart.)

247. W. Rosenhain, F. S. Tritton, D. Hanson, and T. E. Rooney: "Ferrous Alloys Research." *Jnl. I. & S. Inst.*, 1924, No. II.: Part I. p. 85 ; Part II. p. 90 ; Part III. p. 122.

(This report embodies the first part of a systematic research on ferrous alloys, carried out at the N.P.L. under the supervision of Dr. W. Rosenhain. Part II., by Tritton and Hanson, deals with the constitution of iron-oxygen alloys and the effect of oxygen and iron on the mechanical and physical properties of iron. Pure iron containing 0·08 per cent. of oxygen can be rolled with ease both hot and cold, and the rolled material has good ductility in a tensile test. Under notched-bar impact tests, however, the material is very brittle. The low results of these impact tests may be connected with the grain-size of the material, which was large. The absence of impurities no doubt facilitates the production of large grains. Rolled iron rods containing various amounts of oxygen show a marked decrease in ductility with increasing oxide content.

In Part III. Rooney describes a method for the estimation of oxygen in pure iron.)

248. W. H. Hatfield : "Modern Developments in the Metallurgy of Special Steels." *Proc. of the Empire Mining and Metallurgical Congress.* Part IV. "Metallurgy of Iron and Steel," 1924, p. 81.

(Recent improvements in the process of steel manufacture and the manipulation of large masses of steel are referred to, with special reference to the complex phenomena associated with the freezing of large ingots and the degree of heterogeneity due to differential freezing.)

249. A. G. Lobley and C. L. Betts : "The Influence of Gases at High Temperatures upon Iron, with Special Reference to the Formation of Blowholes." *Jnl. I. & S. Inst.*, 1925, No. I. p. 215.

(The experiments described were performed on small quantities of metal, about 300 grammes. It was demonstrated that the presence of carbon dioxide definitely gave rise to blowholes. In the presence of carbon monoxide the metal was very much more sound, though not completely free from blowholes. Nitrogen was found to play no part in causing blowholes, but the effect of hydrogen was very marked. The temperature was also an important factor.)

250. C. H. Desch: "The Deoxidation of Steel." *Jnl. of the West of Scotland I. & S. Inst.*, 1925, vol. xxxii. p. 40; Abstr., *Jnl. I. & S. Inst.*, 1925, No. I. p. 516.

(The principal cause of blowholes is the formation of carbon dioxide liberated during freezing, owing to its very small solubility in solid steel. In very mild steel the sides of the blowholes weld together fairly completely in forging, but in high carbon and engineering steels this welding is either very imperfect or does not occur at all. The bad effects of oxygen in steel are not to be attributed to ferrous oxide alone, but some third element must also be present; Oberhoffer found that inclusions of manganous oxide had a greater effect than ferrous oxide alone.)

251. G. F. Comstock: "Aluminium and Titanium as Deoxidisers." *Iron Age*, 1924, vol. cxiv. p. 1477; Abstr., *Jnl. I. & S. Inst.*, 1925, No. I. p. 517.

(An aluminium-treated steel was found to contain inclusions of alumina, more or less segregated in groups, while an identical steel treated with titanium contained slag inclusions, which were in no case thickly segregated. In the former the sulphide inclusions were found to be arranged in curved streaks, which caused the tensile test-pieces to crack before good ductility was shown. In the titanium-treated steel the sulphides were scattered irregularly in isolated globules.)

252. H. D. Hibbard: "Finishing Melting Temperatures of Simple Ingot Steels." *Trans. American Inst. of Mining and Metallurgical Engineers*, 1925; Abstr., *Jnl. I. & S. Inst.*, 1925, No. I. p. 524.

(The author divided steel into three classes: killed, partly killed, and effervescing steels. He studied the effect of temperature on crystallisation, and particularly on the formation of "chill" dendrites in the outer metal in each case.)

253. N. Parravano and A. Scortecci: "Gases and Oxygen in Steels." *Annali di Chimica Applicata*, 1924, vol. xiv. p. 3; *Revue de Métallurgie*, 1924, vol. xxi. p. 340; Abstr., *Jnl. I. & S. Inst.*, 1925, No. I. p. 525.

(Tests were made by examining samples of open-hearth and electric-furnace steel at 1000° C. *in vacuo* to determine the amount and stable form of oxygen in steels. The presence of aluminium and silicon was not found to increase the solubility of gaseous oxides.)

254. P. Klinger: "An Investigation of the Gases Evolved on the Teeming and Solidification of Steel." *Kruppsche Monatshefte*, 1925, vol. vi. p. 11; Abstr., *Jnl. I. & S. Inst.*, 1925, No. I. p. 525.

(During the teeming and solidification of steel the gases given off were found to consist of carbon monoxide, hydrogen, nitrogen, and carbon dioxide. During effervescence carbon monoxide was the most abundant, but from quiescent steel hydrogen was principally given off.)

255. O. von Kiel and A. Wimmer: "Note on Ingot and Blowhole Segregations." *Stahl und Eisen*, 1925, vol. xlv. p. 835; Abstr., *Jnl. I. & S. Inst.*, 1925, No. II. p. 443.

(Ingots of open-hearth steel were examined with regard to the relation of ingot segregation (phosphorus and sulphur) to blowhole segregation. The more pronounced the segregation in the ingot, the more the blowhole segregation was increased, especially in the case of sulphur segregation. Strongly enriched zones were attributable to blowhole segregation rather than to ingot segregation.)

256. L. Guillet, J. Gallibourg, and Ballay : "Intercrystalline Pipes ; 'Micro-pipes.'" *Revue de Métallurgie*, 1925, vol. xxii. p. 253 ; Abstr., *Jnl. I. & S. Inst.*, 1925, No. II. p. 443.

(The classical explanation of the formation of ordinary pipes is extended to these smaller hair-pipes, the leading causes of which are : the temperature of casting ; temperature differences between the mould and the metal at the moment of casting ; the shape of the casting ; the distribution of the isotherms at each moment during solidification ; the vertical distance between the solidus and the liquidus ; the rate of diffusion of the different constituent elements of the alloy in both the liquid and the solid phases ; the heat of solidification ; the coefficient of thermal conductivity of the solid and liquid phases ; the fluidity of the liquid phase ; and the density of the liquid.)

257. A. Sauveur and V. N. Krivobok : "Dendritic Segregation in Iron-Carbon Alloys." *Jnl. I. & S. Inst.*, 1925, No. II. p. 313.

(Experiments warranted the following conclusions : The presence of oxygen alone in pure iron does not produce persistent dendritic segregation, nor does it appear to affect the behaviour of carbon, phosphorus, or both, in this respect. Phosphorus alone may cause persistent dendritic segregation, and carbon by itself may also cause the same effect provided the cooling is sufficiently rapid to prevent its complete diffusion. Carbon and phosphorus together cause more intense and persistent dendritic segregation ; 0·39 per cent. phosphorus in a 0·17 per cent. carbon steel drives the carbon completely from the fillings into the axes, resulting in pearlitic axes and ferritic fillings. Alpha-iron, after slow cooling, is capable of holding 0·06 per cent. carbon in solution.)

258. Sir R. A. Hadfield : "Sound Steel for Rails and Structural Purposes." *Jnl. of the Franklin Institute*, 1915, vol. clxxix. ; *First communication*, p. 119 ; *Second communication*, p. 663 ; Abstr., *Jnl. I. & S. Inst.*, 1915, No. I. p. 576.

(The author deals with the production of sound steel for rails and structural purposes, and describes his research work on the subject. Comparison is also made between ingots produced by his method and by the ordinary method, the differences in results being illustrated by photographs.)

TEXT-BOOK.

259. A. W. Brearley and H. Brearley : "Ingots and Ingot Moulds." 8vo, pp. 218, with frontispiece and 109 figs. in the text. London and New York : Longmans, Green & Co.

(This book is the principal work in existence dealing with the subjects of casting, freezing, crystallisation, segregation, and inclusions in steel ingots, and it contains a vast fund of information on methods of making steel ingots, the defects which are likely to arise, and the precautions to be taken in order to minimise these as far as possible.)

DISCUSSION.

The PRESIDENT said that the Report was very interesting, and he knew that a great many members desired to discuss it. The Committee, which was appointed some years ago, had done a very practical and extraordinarily fine piece of work for the Institute, which must lead to good results. Dr. Hatfield had said that some of the illustrations shown were a little exaggerated. He himself thought that they might very well stand as a phantasy of a wire-drawer's nightmare.

Mr. E. H. SANITER (Member of Council), as Chairman of Committee No. 5, said that he thought it desirable to explain, on behalf of the Committee, that, as stated on the opening page of the Report, Dr. Hatfield had been authorised to form a Committee to investigate the heterogeneity of steel ingots, and that the credit for the work was due to Dr. Hatfield's initiative and to the great ability and industry of his Committee.

In speaking on the Report, he would like only to dwell upon some of the matters with which he disagreed. The heterogeneity of large ingots was due to two causes—the differences in crystallisation and the segregation of metallic and non-metallic compounds. The beautiful picture which was reproduced in Fig. 1, Plate II., showed that to be a rather terrifying thing; Dr. Hatfield had emphasised that sulphur printing exaggerated in this matter, and it was used for the purposes of illustration, because it emphasised the points it was desired to bring out. But if the figures shown were carefully examined, the mistaken idea obtained at a first glance would be corrected. He would be inclined to say that those ingots might be average ingots in the works where they were made, but they were not average ingots, taking into account the production in the country generally or in the world at large—they were very much better than the average. They had been cast with care; they were perfectly solid steel, and the segregation in them was very much less than in ingots made elsewhere by different methods. In spite of the exaggeration caused by sulphur printing, the figures proved that very material segregation must take place in steel used for very high-class products. The thing to do was to make the steel in the very best possible way and of the greatest possible purity, so that where a segregate did occur the percentage of impurities in it might be unharmful.

With regard to segregation, that was a very complex subject, and one which still required a great amount of investigation. He was referring only to the segregation of the ingot as it froze, not to the minute things that happened, perhaps, at the freezing point locally here and there. The general statement was made that the more rapid the freezing, the less time there was for the complete separation

of the two phases, and the less marked was the heterogeneity of the crystals. He thought that that statement required some qualification. Chilled crystals were very rapidly formed, and the thicker the chilled crystals, the greater the segregation in the internal portion of the ingot. One example of quick freezing to which he might draw attention was in the case of pit samples only an inch or two square and only taking about one minute to freeze. Serious segregation was found in the centre, owing to the squeezing action of the chilled crystals. With regard to the segregation of silicon and manganese, there did not appear to be any material evidence in the Report that those elements did segregate. The figures in Table VII. appeared in some cases to show segregation, but without further evidence he would be very much inclined to attribute that to the presence of oxides of silicon and manganese rather than to the segregation of them in the form of metallic compounds. It was stated that manganese and silicon, due probably to their ready diffusion, were, in fact, shown to be not markedly segregating elements. He was not sure that he understood the meaning of that phrase. Those elements were generally added at a late stage in the making of steel, and surely they were not better diffused than sulphur and phosphorus which had been in the pig-iron and scrap before the manufacture of the steel was commenced. It was highly probable that in the percentages in which those elements were present in the ingots investigated, they were in such a state of combination that their melting points were sufficiently high to prevent them being squeezed out in the same way as the sulphides were.

He next came to the contentious question of sulphur segregation and its connection with manganese. Here he would refer to the analysis given with Example 9 and to Table VII. From the figures in that table it would be seen that there was a much greater segregation of sulphur than of manganese, and it was apparent from those figures that in the case of ingots the sulphur and manganese did not segregate together. It was evident, therefore, that sulphur and manganese were not chemically combined at that stage of the process. In the steel when solid, however, sulphur and manganese were combined together, and it could only be assumed that, at about the temperature of solidification, the manganese was able to rob the iron of its sulphur. At the temperature of molten pig-iron the manganese was combined with sulphur and a desulphurising action took place; if the manganese were combined with the sulphur in steel a similar action would be expected, but that did not occur.

There was one other point to be considered with reference to sulphide of manganese, namely, its high freezing point, which would make it less likely to be squeezed out during the freezing process than another material of a lower melting point would be.

Sir Robert Hadfield (Past-President) congratulated the Committee on the presentation of a thoroughly good and useful piece of British

research work. It seemed to him that there had not been quite sufficient attention paid to the respective characteristics of the soundness of the different materials, which had a great influence on the behaviour of the steel. There were steels which showed a much greater tendency to increased segregation. Some molten steels, while not displaying markedly unsound qualities, were nevertheless liable to the defects mentioned in the Report. It was very necessary to be sure that the steel was sound before pouring into the ingot, and the question was if it were really known whether the steel was sound. The Committee stated that much of the steel dealt with was of the highest quality. Nevertheless, it was quite possible to have steel apparently in a most excellent condition and yet for it to disclose unsuspected defects. He had with him three specimens, all from the same heat of steel. In one case, on pouring the steel into the ingot mould, the result was complete piping or settling. Apparently that steel was perfectly good, but if poured into a greensand mould the result was very unsatisfactory. But, short of that extreme example, there might be an intermediate stage which had not yet been thoroughly analysed or determined by research work. A steel might appear to be perfectly sound and flawless after the ordinary tests were taken, but if it were examined more minutely it would be found to present characteristics which would afterwards lead to the development of segregation troubles, and they often meant in the end those terrible apparitions known as "ghost lines." He was quite aware that the conditions surrounding the manufacture of ingots weighing 150 or 170 tons differed from those appertaining to quite small ingots of 15 or 20 tons, but the Committee might follow up that point with further investigations, by examining a particular ingot and determining the absolute soundness of the particular steel.

Sir William Ellis (Past-President) said that he rather regretted, in view of certain remarks made in the Report, that the audience was not composed of his fellow-members of the Institution of Civil Engineers rather than of the members of the Iron and Steel Institute. He was not at all sure whether the value of a great deal that was in the paper was not much more important to civil engineers, who sometimes rather tended to ask from the metallurgists things which were, at present, really beyond the possibility of production. The leading feature in the Report was that it set before them very clearly Nature's laws of the setting of large masses of steel. Other distinguished steel-makers had appreciated those difficult laws and had endeavoured to control them. The Harmet process went a long way towards proving that a measure of perfection was attainable, given that the dimensions of the presses were relatively large enough for the ingot, but when it came to large masses of 100 or 150 tons, the dimensions of the press disappeared into infinity.

It appeared to him that, owing to the fact that so many leading steel-makers had been asked to take their share in providing the infor-

mation, the Report did away with that objectionable feeling, occasionally experienced by a member, if he discussed certain difficulties in connection with manufacture, that he was having difficulties because he did not know as well as others how to avoid them. The fact was that they were all in that difficulty, and they all had to plead guilty that, while they were doing their best, there was a great deal of imperfection still remaining in the results obtainable. He attached great importance to the representative character of the investigators. None of the figures which were put in the paper surprised him; they had been painfully present from time to time in his own experience during the last five-and-twenty years. But they did emphasise very strongly the importance to engineers who were designing those very large structures for power-stations (a point to which he referred in his Presidential Address before the Institution of Civil Engineers), and who hoped to get a uniform structure in forgings of which the outside diameter might vary from 60 inches to 15 inches, of introducing, wherever it was possible in designing machinery, shafts of comparatively uniform diameter, and of arriving at the larger diameters necessary by means of hollow sleeves. That was a point to which engineers were fortunately giving attention, and which it was very important to develop in order to avoid the very great changes in structure and analysis arising from the original lack of homogeneity in such large ingots. He hoped that the introduction of the paper would take them somewhat further than was represented by that morning's discussion. In the latter part of Section IV. some very controversial points were raised, and the authors had gone deeply into scientific regions. That was quite right, for those things must be looked at scientifically, but there was a great deal which was available for discussion without going into very abstruse scientific argument.

One comment had been made to him. The Report told them what the difficulties were, but it did not tell them how to avoid them. He did not think that was an unfair comment, but it would be unfair to expect the Report to state how Nature's laws might be modified so as to avoid all those difficulties. The Report set out clearly the circumstances which inevitably existed, and existed to a varying extent relative to the dimensions of the ingot, and to a varying degree as regards sulphur in particular, and carbon and phosphorus, and it showed what those elements were likely to do under varying circumstances if they were allowed free play. The problem was to what extent those unruly forces which entered into the production of large ingots could be harnessed, and that was a sufficient task for immediate consideration.

Mr. C. E. Stromeyer (Manchester) said that with regard to the composition of steel, engineers seemed to think that 0·06 per cent. of phosphorus was the permissible limit for that impurity; now, however, it appeared that there must be many structures which nominally con-

tained 0·06 per cent. of phosphorus, but which nevertheless might have patches with very much larger phosphorus percentages. Engineers had therefore been working with steel which was much more unreliable than was expected, but it had not failed.

He had collected records of a number of failures, and amongst them he had come across five cases of failure due to a very high phosphorus content. In one instance, the shell plate of a boiler cracked after it had been in use for thirty-two years, when the phosphorus was found to be 0·161 per cent. More recently the shell plate of a water-tube boiler, after being in use for several years, cracked near the end of the boiler; as usually happened in those mysterious cases, the cracks did not extend into the rivet-holes. Strangely enough, while that plate was being cut out, another plate in the adjoining drum of the same boiler also cracked in the same way. It looked to him as if that were a case of segregation. He had collected forty-seven cases of failures, of which he could explain thirty-four as being due either to phosphorus, nitrogen, or exposure to caustic, and the facts which the Report revealed might perhaps help to explain even the remaining cases.

The study of gases in metals and their analysis had of late made great progress, and it would, therefore, be a great pity if advantage were not taken to analyse the exposed interiors of the available ingots for gases. A continuation of the Committee's labours on those lines might prove even more valuable than the present work.

Mr. H. Brearley (Member of Council) agreed with Sir William Ellis that what the Report presented was a picture of how Nature worked during the solidification of an ingot. That, he thought, was the broad fact which should be taken account of by those who drew up specifications for the acceptance of large forgings made from big ingots. The fact that specifications stated, or implied, that no ghosts should appear in large forgings did not make it possible for the steel-maker to produce large forgings which contained no ghosts. What the steel-maker could do—and what he thought he sometimes did—was to push the position of the ghosts about by varying casting conditions. By experience the steel-maker might find it advisable to arrange that ghosts should occupy a rather deeper position in the ingot, and therefore one likely to become less visible when the forging was put before an inspector! That, however, did not mean there were no ghosts present, and it did not follow that because a ghost was not visible on the surface the forging was therefore any better.

The Report, so far as it dealt with segregation in large ingots, distinguished two kinds: one was the masses of segregation to be seen at the top end of the ingot, and the other was that form of localised segregation to which special attention was drawn in the Report—the **V**-segregate seen in the axis of the ingot and the **Λ**-segregate rising from the inside of the wall of chilled crystals. The large area segregation had, he thought, now become more or less

acceptable to the inspectors. What worried the engineers, and were still a source of continuous anxiety to steel-makers, were the localised **V**- and **Λ**-segregates. Those segregates existed in the axis of the ingot. In the Report it was suggested that by the method of preparation there described the sectioned surface of the ingot was uniformly bright and, apart from the pipe cavity at the top of the ingot, disclosed no other indication of note except, *perhaps*, here and there, slight minor cavities and looseness along the central axis. He would suggest that the Committee ought not to use the word " perhaps." They would, he thought, always find minor cavities associated with the **V**-segregate, though if an ingot were cut right down the centre with a saw, or a tool of some other kind having a considerable thickness, the minor cavities would not always be found, because the axis of the ingot had been machined away.

It was stated in the Report that the **V**-segregates were carried down from the head of the ingot, and that that accounted for them adopting the **V**-form. That statement was at variance with all that he had observed. If the **V**-segregate depended on the amount of steel in the feeder-head of an ingot, then, in an ingot made without a feeder-head, **V**-shaped segregates would not be expected, but they did, in fact, occur. From the pictures presented with the Report it was also perfectly clear that the **V**-segregate material had not come from the feeder-head. On any sulphur print it would be noticed that just below the feeder-head there was a length of 6 inches or more of the ingot which did not contain any **V**-segregates. Could the Committee explain how the segregated steel passed from the feeder-head into a lower part of the ingot without forming **V**-segregates in the part immediately below the head ?

The Report referred to the fact that the chilled crystals in an ingot were always inclined upwards, and it was stated that " this upward direction is given to the crystallites first forming at the chill surface, as a consequence of very local outward curvature of the isothermals in the steel at the outer edges of the rising surface." He did not understand what that meant, and, further, he asked separately two members of the Committee, who also could not explain it to him. That being the case, he was not surprised to find that Section IV. had not the unanimous support of the Committee. It was clear that if any single crystal protruded horizontally into molten metal it might lengthen by growing forward, and thicken at the end by growing both upwards and downwards. The chilled wall in a freezing ingot (apart from the effects exerted by the top and bottom of the ingot mould) began to form earlier in any plane than in the plane immediately above. The growth of chill crystals on two adjacent planes might be represented by the middle finger and the index finger of the hand held horizontally. The chill crystal represented by the middle finger might grow forward, and at the extreme end could thicken upwards. When, therefore, the chill crystal represented by the index

finger grew forward it must turn upwards over the thickened end of the crystal lying immediately below it. The discontinuity involved in that description did not, of course, exist. The inferior crystal had a continuous chance to thicken upwards; the superior crystal must adapt itself to the predetermined condition, and therefore inclined upwards. If that explanation were correct it should be feasible under special conditions to cause chill crystals to incline downwards. That could be done by putting a water-cooled band around the middle of an ingot mould. Under those circumstances the chill crystals above the water-band were inclined upwards, and those below the water-band were inclined downwards. For that explanation and a demonstration of it, both in metal and wax ingots, he was indebted to his brother.

Dr. Harold Moore (Woolwich) said that the merits of sulphur printing as a method of studying segregation in ingots, forgings, &c., were indicated in the Report. He was under the impression that some two years ago he had heard Dr. Hatfield speak in a very disparaging way of the use of sulphur prints, and he would like to ask the Committee to say what were really their present views on that matter. No doubt, further investigation would be carried out on the subject of heterogeneity in ingots, and it was essential to know what were the sound methods of investigation which might be employed. The Report might be regarded as a steel-makers' Report, but it was also a quite unbiased record of the present position.

Dr. Walter Rosenhain, F.R.S. (National Physical Laboratory), said that the Report presented itself to him from several points of view. It was first of all to be welcomed as an example of co-operative research carried out by steel-makers. There could, of course, be no question as to the competency of the Committee, and no doubt everyone would appreciate that. When they came to the bearing of the Report there were other points of view which had to be considered. The Report had been put forward as propaganda for inducing engineers to modify their apparently unreasonable requirements. He had no doubt whatever that the requirements, not perhaps of the engineers, but of some inspectors, were sometimes unreasonable. At the same time, the steel-maker must take the necessities of the engineer fully into account.

It had been stated, with regard to the formation of the segregates, that the steel-maker had no control over the laws of Nature, but what was being demonstrated here was not a law of Nature but the phenomena which resulted from those laws under particular circumstances. It was only when those laws were known and the circumstances under which they were allowed to operate became familiar, that any kind of control would be secured. On reading Section IV. of the Report it seemed clear how little was known about the phenomena which occurred in the solidifying of a large mass of steel, particularly when that mass of metal

contained a number of constituents behaving in a variety of different ways, and the conclusion to be drawn was that the knowledge not at present available must, somehow or other, be obtained. The Report was a step in that direction, because it showed clearly the kind of defects and difficulties which had to be encountered. He thought that the matter might be put perhaps a little more precisely. The things that were wanted were obviously a knowledge of the equilibria of the alloys of iron. Further than that, it was necessary to know something more of the changes in physical properties which liquid iron in the first place, and afterwards liquid alloys containing various elements, underwent prior to reaching the freezing point.

Finally, there was another aspect of the question, to which Sir Robert Hadfield had referred, at least by implication, the question, namely, of the part played in all those phenomena by the presence of gases in the liquid steel in solution or in suspension, about which very little indeed was known at the moment. In any case, the real lesson emerging from all that study was the need for much more detailed and accurate information than had hitherto been obtained by the mere examination and measurement of ingots.

Professor Cecil H. Desch (Member of Council) said the Report testified to the great improvement in the quality of ingots which had been brought about in recent years by the adoption of better methods of casting. The first impression on reading the Report, and especially on examining Tables VII. and VIII., was that the variation in the concentration of sulphur and phosphorus in different parts of the ingots was less than might have been expected. Much greater variations were shown by the ingots described by Mr. Talbot in 1913, and by the American Committee which reported to the International Association for Testing Materials in 1912. The casting of ingots with hot tops had had the effect of lessening the extent of the segregation throughout the ingot as well as of increasing the fraction of the ingot which consisted of sound steel.

It would be of interest to know what was the nature of the remarkable segregated mass in ingot No. 9, illustrated in Plate XV. The local dendritic structure was very pronounced, and the high sulphur and phosphorus did not seem to account completely for the structure. Perhaps an examination of the area under a higher magnification might reveal its nature. It was likely that the dendrites were of relatively pure metal, with the impurities entangled between the branches, so accentuating the etching contrasts, but it was not clear why such a structure had occurred at a few spots only in the ingot. That ingot was cast in loam, and therefore might be presumed to have cooled more slowly than the others.

It would seem that knowledge of the process of freezing was really more complete than had been assumed by the authors. The effects of varying distances between the liquidus and solidus were well known ;

the general process of freezing had been well dealt with by Mr. Brearley in his book on ingots and ingot moulds, and it was only proposed to deal at the moment with certain points on which quantitative information was already available.

The change from the columnar to the equiaxed type of crystal was most easily accounted for by the difference, established by the work of Miers and his collaborators, between metastable and labile ranges of crystallisation. The separation of the first crystals from the liquid undoubtedly occurred under metastable conditions, the crystals which had already formed bringing about further crystallisation by contact. As cooling proceeded, a stage was reached at which fresh nuclei appeared spontaneously in the midst of the liquid. It had been proved for salts and for molten organic substances that the two types of crystallisation might present themselves in the same mass. It was also known that whilst the columnar form of crystal was common under metastable conditions, the labile shower often consisted of radiating or star-shaped crystals. The evidence contained in the Report and in other memoirs on the same subject went to show that the equiaxed crystals had the form of octahedral branched skeletons, which made their appearance in the midst of the liquid, and then fell through it, accumulating as a conical heap in the lower part of the ingot. Such crystals would readily free themselves from impurity, and would consist of iron containing a relatively small quantity of the dissolved elements. In falling through the steel they might easily entangle particles of slag, dragging them down to the lower levels, as shown by Mr. Dickenson in his paper. As the equiaxed crystals were formed quite independently of the columnar crystals there was no union between the two, and the liquid which was trapped at the surfaces where the two types met was likely to be peculiarly rich in impurities, that being, in fact, one of the principal seats of segregation. It did not seem necessary to assume that globules of manganese sulphide might act as nuclei for the coalescence of particles of impure mother liquor, since the dissolved impurities naturally accumulated in those portions which were the last to freeze, and the sulphide particles, although insoluble, were continually rejected by the growing crystals and pushed before them, so that they also collected in the portions of liquid which remained longest unfrozen. The one point of difficulty was, perhaps, that the insoluble particles of sulphide and those of slag might be expected to behave in the same way, so that the greatest amounts of sulphur and of slag inclusions would be found in the same regions, and that did not seem to occur. It might be that the formation of sulphide particles was not so simple as was commonly assumed, and experience with cast-iron would seem to show that suggestion to be true.

The doubt expressed as to whether the crystallites were heavier than the liquid, so that they would fall during the process of freezing, was unfounded. It was certain that iron, and presumably steel, contracted on freezing, and it was not difficult to calculate the amount of

contraction. That might be done in two ways. It was known that δ-iron, existing above 1410° C., was identical with α- and β-iron in its physical properties, allowance being made for the difference of temperature. The linear expansion of iron up to 750° C. was given by the formula:

$$l_t = l_0 (1 + 0{\cdot}04117t + 0{\cdot}0852t^2).$$

The values for the density calculated on that basis, assuming the density of iron at 15° to be 7·88, were given in the table below. Extrapolation to the melting point, 1535° C., gave the value 7·22. On the other hand, the figures for the space lattice constant determined by Westgren, which were also given in the table, might be taken. Extrapolation to 1535° C. gave a density 7·33. If, however, the weight of an atom of hydrogen were taken as $1{\cdot}663 \times 10^{-24}$ grammes, as given in the International Critical Tables, Westgren's figures led to a density at atmospheric temperatures of 7·93, which was higher than that found by experiment. If, instead, the value 7·88 were taken, and the figures lowered accordingly, the density at the melting point was found to be 7·28. It was to be noted that the density of γ-iron did not enter into the calculation. Within the γ-range the iron diverged from the curve, but returned to it again on its transformation into the δ-modification, the condition being merely an incident in its history during heating or cooling.

Density of Iron at Various Temperatures.

Method of Derivation.	15° C.	800° C.	1450° C.	1535° C. (extrapolated).
Expansion formula .	7·88	7·59	7·27	7·22
X-ray data . .	7·93	7·69	7·38	7·33
X-ray data (corrected)	7·88	7·64	7·33	7·28

The density of liquid steel was determined directly by Professor Benedicks and his colleagues[1] to be 6·92 at 1550°. That steel contained from 0·2 to 0·3 per cent. carbon, the quantitative influence of which on the density was unknown. If the reasonable assumption were made that it lowered the density of the liquid and the solid metal in about the same proportions, the value 6·94 would be obtained, which meant a contraction on freezing of about 4 per cent. for pure iron. It was not likely that the figures for steels would be very different.

The authors invoked, as one of the causes of segregation, the phenomenon known to physical chemists as the Soret effect, but which was first observed by Ludwig in 1856. It had been shown theoretically, and confirmed by experiments on solutions in water and organic solvents, that the concentration of a dissolved substance in a mass of

[1] C. Benedicks, D. W. Berlin, and G. Phragmén, *Carnegie Scholarship Memoirs*, 1924, vol. xiii. p. 166.

solution which was not at a uniform temperature was not constant, but was greater in the cooler parts than in the hotter. Attention had been drawn to that effect as a factor in the segregation of steel ingots by Professor Benedicks in 1925.[1] The Ludwig-Soret effect was shown to play an important part in certain forms of metallic corrosion, and it was extended, although only in a qualitative manner, to the case of ingots. Dr. S. W. Smith had lately made a similar application to segregation in non-ferrous alloys.[2] There was an extensive literature on the subject, and in particular many efforts had been made to find in that effect the cause of segregation in rock magmas, beginning with the work of Teall.[3] The explanation was definitely rejected for igneous rocks by Bowen,[4] after a very careful investigation, because the differences of concentration were altogether too small to account for the observations. Applied to the facts described in the Report, it might be taken that the existence at one point of twice as much phosphorus or other impurity as was found at another point of the same ingot had to be accounted for. It had been assumed that the product of the concentration and the absolute temperature was a constant. Benedicks had shown that that was not strictly correct, and that it was really the thermodynamic potential, which involved the pressure, which was constant, but that would not appreciably affect the results. A simple calculation showed that to account for such a difference in the phosphorus content, the difference of temperature between neighbouring parts of the same liquid metal would have to be about 1700° C. Even to account for a difference of phosphorus content of 10 per cent., say 0·04 and 0·044 per cent., would need a difference of temperature of 150° C. The Soret effect was too small to have much importance without the assumption of temperature gradients far in excess of anything that was possible in practice. It did not seem necessary, however, to take such an effect into account, as the known facts of crystallisation from a molten mass were quite sufficient to explain the structures which were observed.

There was one other point which called for criticism. It was suggested that the liquid metal became very viscous as it approached the freezing point. There was no evidence for such an assumption. The viscosities of molten metals were low, being usually less than three times that of water, and that was the case even close to the melting point. Whilst there were no data as to the actual viscosity of molten steel, there was no reason to suppose that it differed in that respect from other metals, and common experience in the works would suggest that steel was highly fluid. It thus differed from molten silicates, which were extraordinarily viscous when first melted, and only

[1] C. Benedicks, *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1924–25, vol. lxxi. p. 597.

[2] S. W. Smith, *Transactions of the Institute of Mining and Metallurgy*, 1926.

[3] J. J. H. Teall, "British Petrography," p. 394. London, 1888.

[4] N. L. Bowen, *Journal of Geology*, 1915, vol. xxiii.

became fluid at temperatures far above their melting point. That was explained by their high degree of molecular association, but metals, including steel, were known, from the lowering of their freezing points and from other facts, to consist mainly of single atoms. Their viscosity should therefore be low.

Mr. T. HENRY TURNER (Birmingham) said that the Report dealt largely with the heterogeneity of steel ingots, as indicated by the analyses of drillings, which gave only average results for the ½-inch or ¾-inch drills used. He desired to add to the discussion from the point of view of the metallurgist defending the interests of the consumer. It was known that the analysis of a large ingot varied from place to place, but what no metallurgist could honestly say was whether he knew that an ingot showing ghost lines when forged was suitable for certain purposes or not. That was always a debatable question between any two metallurgists, the steel-maker leaning to one side and the consumer veering, from caution, towards the other. He did not agree that a sulphur print exaggerated from the point of view of the consumer. On the other hand, analyses undoubtedly minimised the real danger confronting the consumer, if the article when finished were to be a turbo-rotor or some other rotating part subject to numerous alternations, and likely to fail under fatigue. Under those conditions it was not slight differences in chemical analysis, but the local differences caused by segregation in its worst possible form—*i.e.* actual manganese sulphide or some such inclusion, which were responsible for the mischief. The sulphur print showed that, where the analysis might overlook it, and he was certain the consumer would not agree with the statement that the sulphur print exaggerated the danger. With regard to carbon and silicon the analyses were probably reliable ; but so far as non-metallic inclusions and the danger of fatigue were concerned, they could not be so regarded.

It should be pointed out that the Report dealt only with carbon steels, and that the heterogeneity was worse in many alloy steels. The ingot corner segregation was a real danger in guns, in large boiler forgings, in large rotors where slots were cut, and in discs. The cone of segregation at the bottom of a large ingot created a problem when it came up in the finished forging as dots on the journal at one end of a large rotor forging. Those were non-homogeneities which were to be found especially in alloy steels. Therefore the Report painted the picture somewhat too brightly for engineers or the users of the steels. Again, it did not indicate the serious difference caused by variations in grain-size in the finished article, a physical difference in composition, which vastly affected the physical properties. In one of the big ingots, after forging, the grain-size would be at least ten times as large in the core extracted from the centre as at the outside.

The flow had puzzled him, as it had done most other people, because in a beaker of water one would expect the flow to go down, cooling at

the side, and up in the centre, but the steel in the ingot mould went down in the centre and up at the cooler sides, which was just the reverse of what might be expected. Was it not possible that that was partly caused by the momentum of the steel pouring into the centre of the mould, giving an initial direction of flow? It must be remembered that in all the cases here reported the ingots were poured from the top, with one nozzle. Therefore the stream flowing down in the centre carried a momentum, causing an upward current all round the sides. As Dr. Desch pointed out, the density difference might tend to perpetuate that flow in the direction indicated. Possibly someone among the authors of the Report might know what happened when an ingot was poured with four different nozzles fairly near the side. Was there, then, the same inverted and normal cone of segregation? In the ordinary ingot two systems of cones of segregation could be observed—the one at the side pointing upward, and the other in the centre pointing downward. Was that reversed when the ingot was poured from the bottom? Personally, he did not think it was, but it was a point of importance.

As a simple method of testing the heterogeneity, surely the ingots might be examined by density determinations. If the ingots were still available, that could yet be done. Presumably the best of the steel would be the densest; where there were pinholes in the centre, or where the segregation was large, there would be quite a marked difference in density. He suggested that simple density tests might be made on specimens cut near where the analysis samples were taken.

Dr. S. W. Smith (London) said that Dr. Desch having referred to a discussion which had recently taken place at the Institution of Mining and Metallurgy on a form of segregation with which metallurgists were confronted in non-ferrous metals, there were a few remarks which he would venture to make on that point, which he thought had some bearing on the question of segregation in steel. The form of segregation in non-ferrous metals to which reference had been made had, for more than fifty years, been known and referred to as "liquation." The peculiarity of that behaviour was that the direction in which the constituents segregated in a chilled casting was exactly the reverse of that which might be expected from a consideration of the equilibrium diagram—the exact reverse, in fact, of the direction indicated by the authors in their reference to Fig. 8. The authors' remarks were only applicable to the "ideal" condition of solidification, where heat was withdrawn uniformly from the mass, and they did not take into account the effects of a temperature gradient within the cooling mass. The facts regarding the behaviour of "liquation" were that, in the great majority of cases of non-ferrous metals which had been examined from that point of view, the constituent which lowered the freezing point of a mass of some particular composition tended to segregate, not towards the centre of the mass, as might be expected, but towards the periphery, *i.e.* towards the portions which were adjacent to the chilling

surfaces. That apparent contradiction of theory by actual facts had been explained, primarily, by the influence of the temperature gradient from the chilling surface to the interior. The temperature gradient was chiefly responsible for the gradations of composition which were found to occur on passing from the chilled surfaces of non-ferrous metal castings to the interior. Professor Carl Benedicks, to whom Dr. Desch had already referred, had recently drawn attention to the operation of that phenomenon in the distribution of the constituents in steel and cast-iron. The physical behaviour to which Dr. Desch had referred in the course of his remarks as the "Soret" effect was still of debatable application as an explanation of "liquation," but the fact of liquation occurring in the way indicated—namely, in the reverse direction to that which might be expected from the equilibrium diagram—was an undoubted fact in non-ferrous metals, and it seemed to him unthinkable that some evidence of that occurrence should not be found in the case of steel also. A careful examination of the authors' results appeared to him to confirm the views which Professor Benedicks had put forward, although, as far as he could gather, the authors were not aware of it; at any rate, they had not discussed it. The remarks of the authors which came nearest to that question were: "Whilst dealing with these matters it is well to put on record the possibility of another influence in producing heterogeneity. It may be shown that, as a result of the known laws governing osmotic pressure, temperature gradients in a solution will influence the distribution of the solute." Farther on, however, they dismissed the consideration of that question by saying: "As to whether liquid iron solutions such as those under discussion can be considered to behave in an analogous manner can only at present be considered as within the realm of conjecture." But, curiously enough, the authors had not attempted to apply their own results to the possibilities which were indicated by their remarks in the preceding paragraphs. Almost any of the examples given by them might be taken to illustrate the view that "liquation" had been operative during solidification. Dr. Hatfield had indicated, in his opening remarks, the evidence of segregation longitudinally from the bottom to the top, but he (Dr. Smith) would like to draw attention to the evidence afforded of segregation laterally, *i.e.* from the interior towards the chilling surfaces. Taking, for instance, Example 5 (Plate X.), if the analytical figures were examined for either element, except perhaps silicon, it would be found that those which were adjacent to the chilling edge, certainly in the lower half of the ingot, were all higher round the chilling edges than at the centre, and in many cases actually higher than the mean value of the ingot as a whole. That was quite in accordance with the behaviour of non-ferrous alloys. Enrichments were found at the chilling surfaces which were considerably above the average compositions of the whole mass. The authors' results afforded evidence of this behaviour in the case of carbon, manganese, sulphur, and phosphorus, and he would venture to suggest, therefore, that some consideration

might be given to the possible operation of the phenomenon of "liquation" in relation to the segregation of the constituents of steel and cast-iron.

Dr. D. Hanson (National Physical Laboratory) said he desired to ask the Committee to amplify one or two points. The statement was made that in their opinion very rapid cooling tended to suppress segregation; there was no time for the phases to separate, and the crystals, therefore, had a composition practically the same as that of the liquid. That was contrary to general experience in connection with the solidification of metals. He suggested that what really happened was that segregation actually took place, but on a scale so small that it would not show on a specimen etched for macroscopic examination; it would, however, be visible under the microscope. He suggested that actually the segregation was present on the outer surface in the highly chilled part, but that the segregated parts were so intimately mixed that they did not show unless they were looked for very carefully. With regard to the association of sulphur with carbon and phosphorus, the Committee suggested that the globules of sulphide might act as nuclei for the coalescence of the minute particles of the impure liquid. He would be much obliged if they would amplify that point, because he found himself unable to understand exactly how they pictured that process to happen. He also ventured to suggest that any nuclear action of that kind was not necessary. The sulphur was, at the temperature of solidification, presumably present in the form of small globules in the molten steel and tended to associate itself with the liquid portions. It maintained that relationship with the liquid portions during the process of solidification, so that it automatically found itself, when the ingot was solid, in the last portions that were frozen, *i.e.* in the portions highest in phosphorus. Superimposed upon that segregation there was the segregation of sulphur in the liquid state, so that he thought the complete results could be accounted for without bringing in any other factor than those two. The presence of a central zone of weakness was also noted, and the suggestion made that it was due to the boundary between two zones of crystallisation. That no doubt would give rise to such an effect, but he would like to ask if the Committee did not think that the main cause of that central zone of weakness was unsoundness due to the drawing away from the centre of the last parts of the liquid to solidify, to fill in the gaps caused by the solidification and contraction of neighbouring zones. Although the boundary between the two zones of crystallisation did sometimes cause weakness, it did not give rise to the kind of weakness that was usually found in the centre of steel ingots.

Mr. E. A. Atkins (Warrington) said there was some indication that the ingots dealt with in the Report were rather better made than average ingots. If that were so, he would like to see some results

obtained from ordinary ingots in the various steelworks, and also some results from ingots that had been badly made, because that information would serve as a guide. He was particularly interested in the relationship of the sulphur and the manganese; it seemed rather a mystery that the sulphur could be about four times as much in one part as it was in another, whereas there was very little change in the manganese. He had in his possession particulars of a case relating to some drillings from a 2-inch square billet. The centre square inch of the area contained 0·10 per cent. of sulphur, while the other three square inches contained 0·015 per cent.; that meant that the centre 1 inch of area contained five and a third times the amount of sulphur in the outside areas. On the other hand, the manganese simply went up 25 per cent. It looked to him as if, in the cooling, the sulphides, whatever they were, must change their composition during their migration. Röhl's work proved that the sulphides were complex. Tests which he had made on etching had compelled him to believe that where sulphur existed in a very segregated form a large proportion was in the form of iron sulphide. That being so, it seemed to him that the steel would be in a very dangerous condition owing to the sulphide, and such a fact might explain some of the breakages that were often obtained in bars, and regularly experienced in connection with wire-drawing, when sulphur segregated in that form. He was sorry that the classical work of Röhl on sulphides had not been amplified by the authors; he believed that had it been followed up by work with actual ingots some extremely useful information would by now have been obtained. He was sorry that not more information in regard to the interpretation of the facts had been given; he thought it would prove advantageous if each member of the Committee gave his own opinion, in order that the members might possibly derive useful information from them. An additional report of a practical nature, showing how to get minimum heterogeneity in ingots, would be most useful.

Dr. W. H. Hatfield, in reply, said he desired to say on behalf of the Committee how very much they appreciated the discussion and the criticism which had been received. Broadly speaking, it was quite clear that the members accepted the data put before them as being reasonably indicative of the homogeneity to be expected in ingots of various sizes. He had hoped that in the discussion they would have received contributions of the nature of comparisons with data existing in other works with which the Committee had not come into touch in the course of their inquiries.

In summing up the discussion on the paper, he found that there was no discussion on the introduction. In regard to Section II., on the methods employed in studying the sectioned ingots, the only question raised related to sulphur printing. Dr. Moore rather accused him of being severe on the sulphur printing method in some remarks he made two years ago. He did not remember them, but he would repeat the

offence. The sulphur method of printing was unreliable, in the sense that it grossly exaggerated any difference in composition that occurred, a statement in regard to which he was sure he would be supported by each member of the Committee, who would be very glad to demonstrate the fact to Dr. Moore or any other member. If Dr. Moore liked to take a steel containing 0·02 per cent. of sulphur and a hard steel pointer, and write his name on the polished surface, he would find that his name would come out very black indeed; in other words, the sulphur print did exaggerate grossly. He admitted that it was a very useful method, but it was absolutely qualitative: it must be either black or white.

With regard to the general points raised in the discussion, he thought the Committee must handle them as a collective body. He did not think there was anything he need refer to at the moment, except to say that of course the authors very much appreciated Mr. Saniter's remarks as Chairman of the No. 5 Committee. They were largely in agreement with what Sir Robert Hadfield and Sir William Ellis had said. Sir William Ellis had raised the question of the Whitworth and Harmet ingots. The Committee deplored the fact that now that the investigation had taken the somewhat quantitative lines it had, they were not able, since those processes had passed away, to examine ingots which had been subjected to the Harmet and Whitworth method of pressure, because it would have been interesting to have put the quantitative effect of that procedure on record. One of the speakers had pointed out that the 172-ton ingot to which reference had been made was not scrapped. That was a fact; it was not. To enable a sufficiently complete picture to be made of the ingot, he commended to the attention of the members the facts disclosed by that examination. It was a very interesting fact that that particular ingot provided one of the most important items ever produced in the engineering world, which had been in operation for some considerable time. In other words, that 172-ton ingot, whatever the degree of its homogeneity, had produced a forging which had given a very good account of itself. That, he thought, was valuable collateral evidence. Mr. Turner had compared water in a beaker with steel freezing in an ingot. If Mr. Turner would reconsider the matter from the point of view that the water in the beaker was not freezing, but that the steel was, he would find a very adequate reason for the dissimilarity in behaviour.

Dr. Desch had made a very valuable communication, which the Committee very much appreciated. On behalf of the Committee, he had great pleasure in inviting Dr. Desch to elaborate still further the interesting line which he had taken up, with a view to making deductions concerning the change of density at the point of freezing. It was a fundamental point on which the Committee had at present no data, and if Dr. Desch could follow up his calculations in the matter the Committee would be extremely indebted to him.

CORRESPONDENCE.

Dr. C. Benedicks, Hon. Vice-President (Stockholm), wrote that mention was made of the possibility that temperature gradients in a solution would influence the distribution of the solute. As a matter of fact, he[1] had shown, by means of segregation data obtained on iron, steel, and pig-iron, that that effect, the *Ludwig-Soret effect*, did exist for the iron alloys, and was fairly accentuated in the case of large ingots—where a considerable temperature gradient might occur in the liquid state. Later an excellent compilation of data was published by S. W. Smith,[2] giving new evidence that the effect exerted a considerable influence in non-ferrous alloys. The knowledge of that effect—which implied concentration differences contrary to what would be expected from the equilibrium diagram curves—was important in elucidating at once the so-called "inverse segregation," the explanation of which gave rise earlier to great difficulties, such as the *ad hoc* hypothesis that the eutectic which concentrated in the centre of an ingot, before the final solidification, travelled to the outside of the ingot.

In the discussion of Dr. Smith's paper it was pointed out by the present writer that the Ludwig-Soret phenomenon in alloys might be strongly marked in those alloys possessing (at lower temperatures) a liquidus curve with a slight slope. The addition of a third element would, by diminishing the slope, cause the Ludwig-Soret effect to increase (as was the case with the addition of nickel to Ag-Cu alloys); on the contrary, the addition of an element which increased the slope of the liquidus curve lowered the Ludwig-Soret effect (as the addition of manganese to the Ag-Cu alloy).

As for carbon steel, it was known that the addition of silicon and manganese respectively increased the slope of the liquidus curve: hence they might be expected to reduce the Ludwig-Soret effect. That, in his (Dr. Benedicks') opinion, was the rational reason why the addition of silicon and manganese and aluminium exerted so beneficial an influence on the homogeneity of steel ingots. The fact—otherwise peculiar, in view of the extremely detailed data on large ingots given in the Report—that here so little was seen of the Ludwig-Soret phenomenon, was at once explained from that point of view. From the analyses given in Table I., showing generally fairly high manganese and silicon contents, Example 9, possessing the lowest manganese (0·51) and silicon (0·04) of all, appeared to be almost the only steel where a sensible Ludwig-Soret effect was to be expected. The effect there was quite

[1] C. Benedicks, *Transactions of the American Institute of Mining and Metallurgical Engineering*, 1925, vol. lxxi. p. 597.

[2] S. W. Smith, *Bulletin of the Institution of Mining and Metallurgy*, 1926 (Feb. 25).

plain: in the outer layer of the ingot—where the Ludwig-Soret phenomenon was to be observed—the carbon content was lowered on an average from 0·25 to 0·21, sulphur from 0·025 to 0·0185, and phosphorus from 0·061 to 0·0495, when proceeding from the bottom to the top; the interior part of the ingot showed the opposite changes—as was almost universally the case.

Another instance of the occurrence of the phenomenon might be noted in Example 7 (Si 0·12), where, in spite of a considerable manganese content (0·83), the outer layer likewise showed a very plain "inverse" segregation, normal to a carbon steel: carbon from 0·385 to 0·36, sulphur from 0·0385 to 0·025, and phosphorus from 0·037 to 0·027.

It seemed to be admitted in the Report, as demanding no explanation, that the iron crystals or dendrites growing into the fluid mass had a columnar form. That, however, was scarcely evident; *e.g.* in the electrolytic precipitation of iron, crystals grew similarly in one single, preferential direction, but no separation into columns was observed comparable to that in the solidifying ingots. The writer pointed out earlier—in the discussion of Professor Desch's report on solidification of metals [1]—that the columnar structure, like the columnar structure in basalt, was probably due to local convection currents, occurring on cooling; thereby attention was especially directed to the interesting work of Dauzère.[2]

In order to substantiate this view, a few observations on molten beeswax had been made. When solidified in a small shallow porcelain basin—after heating over a Bunsen flame—as a thin layer (about 7 millimetres), the free surface exhibited a very characteristic cellular structure, due to the boundaries being slightly depressed (being downward portions of convection currents). The formation of those local currents was in conformity with the basic principles of thermodynamics: the heat transfer from the bottom part to the colder zone was much more accelerated by the formation of local convection currents than by the formation of one single, regular convection current—which, of course, would anyhow transport more heat than the liquid if stagnant.

Further, by melting beeswax between two glass plates, forming a cuvette (a rubber tubing in U-shape forming the side walls), and holding in an oblique position, it was easy to show that the solidification on the upper plate—easily seen on account of the opacity—frequently did not lead to the formation of an even frozen layer; instead it would occur along roughly parallel lines, sometimes bifurcated, which were due to local currents and not to crystallisation, as proved by the fact that the columns were clearly visible against a suitable background even before any solidification took place, on account of variations in the refractive index. They seemed to afford a fairly good analogy to the columns formed in freezing iron.

[1] *Journal of the Institute of Metals*, 1919, No. 2, p. 241.
[2] *Comptes Rendus*, 1919, vol. clxix. p. 76.

The factors influencing the thickness of the columnar zone 1 were enumerated in the Report as follows : temperature of the liquid steel, rate of teeming, temperature, thickness and nature of the mould, size of the ingot, and composition of the steel. To those numerous factors was added the forming of a gap between the cooling ingot and the mould. He had nothing to object to in this, but it would be desirable to elucidate that matter by adding that the generally remarkably sharp limit of the columnar zone, according to all probability, *simply corresponded to the heating up of the previously cold mould to a fairly uniform temperature.* Up to that moment heat was abstracted from the molten iron by the heating up of the mould, at a considerable speed, on account of the high thermal conductivity of the metallic mould ; after that moment heat was abstracted only in so far as it was dissipated from the mould itself by radiation and convection in the air. That explanation appeared to be so natural that it ought to be preserved until proved insufficient. Of course a direct proof of its essential correctness would be highly desirable. It was to be regretted that no evidence in that direction was given in the Report. According to that view the essential point might be said to be the heat capacity of the mould, combined with its heat conductivity. The temperature must be considered to be next in importance. As a general rule it might be expected that the thickness of the columnar zone would increase with decreasing temperature of the liquid steel. Thereby, however, it was necessary to assume that the iron possessed a comparatively high temperature. If that were not the case, and the temperature of the liquid were very near the freezing temperature, then of course solidification might start from nuclei in the liquid iron, and the columnar zone would not nearly reach the thickness which would be found if solidification did proceed only from the periphery.

An experiment described by J. Descolas and E. Pretet, referred to in the report, regarding the influence of the thickness of the mould, gave no definite result. That strikingly sharp limit, which so frequently occurred was one of the problems which primarily required further investigation.

Mr. Henry D. Hibbard (New Jersey, U.S.A.) wrote that this admirable Report might well have been entitled "Segregation in Killed Steel Ingots," for that was what it really covered. The statement was frankly made that "incompletely killed steel will not be dealt with," and rimming steel was not even mentioned.

In its field the Report gave much of value, though a good deal was in confirmation of things already known. Then, beginning as it did with the ingot, the history of the steel and the methods and manipulations employed in producing the ingot were ignored, which left the practical steelmaker lacking much that he would have liked to know. The omission was, of course, intentional, for the members of the Committee could, no doubt, have supplied the deficiency. The greatest

benefit from the Report thus accrued to the makers of the ingots, who alone knew how they had been made.

Section IV. was particularly interesting and instructive. Another section devoted to production methods and to means for lessening segregation would have been most valuable.

Segregation occurred in different ways and degrees, according to whether the steel were killed, partly killed, or rimming, being least marked when it was killed. Steel was intentionally made in all those ways, and " off " heats of each kind were sometimes made unintentionally. To have dealt with all of those would indeed have made the Report much longer, but also more valuable.

The rules as to the segregation of elements in steel seemed to be as follows:

1. Those alloyed with iron segregated relatively little. Such included silicon, titanium, aluminium, and manganese. With the possible exception of the last named, they also tended to check segregation of other ingredients. Any aluminium or titanium added, and presumably some of the former was added in some if not in all cases, should have been mentioned in the Report.

2. Elements chemically combined with iron tended to segregate strongly if permitted. They included carbon, phosphorus, and sulphur, as the Report clearly showed.

Mr. Cosmo Johns (Sheffield) wrote that further consideration of the data given in the Report had only served to impress him still more with its great value. Though heterogeneity in steel ingots had long been known it was only now that a number of examples were available, in an accessible form, representing the regular practice of the leading British manufacturers of special steels up to and including the largest ingots made in this country.

Having regard to the use made of sulphur prints in detecting heterogeneity in steel, it was important to note that sulphur was the element most prone to segregate, and as a sulphur print exaggerated the heterogeneity its interpretation required considerable experience. When dealing with the product of experienced manufacturers where the correct discard had been made, it was safe to conclude that the steel was more homogeneous than a glance at a sulphur print would lead an inexperienced observer to expect. A study of the data given in the voluminous Report revealed the progress that had been made, in this country, in producing masses of steel of the weights described with so little heterogeneity in the parts of the ingot which passed into service.

In the course of the verbal discussion Sir Robert Hadfield referred to the importance of the gaseous constituents of steel and their effect on its properties. He (Mr. Johns) published[1] an account of a working hypothesis which, in his experience, afforded an explanation of the

[1] *Journal of the Society of Chemical Industry* (Review), April 30, 1918.

origin of the gaseous and solid oxygen compounds found in steel. Had the Committee been able to include in their Report an account of the mode of distribution of the occluded gases and of the silicates in typical ingots, it was possible that more light would have been thrown on the obscure problem of the causes that led to heterogeneity in steel ingots and castings.

It was strange to find that the authors of a Report like that should have repeated the old doubt as to the nature of the volume change when steel passed from the liquid to the solid state. Apart from the work of Benedicks, referred to by Professor Desch in the verbal discussion, the question could be settled by observations of the actual process of freezing in the steelworks. Assertions that liquid steel expanded on freezing, like water, could be found distributed throughout scientific literature in this country and abroad. An error once published was most difficult to overtake, and in that case the error had important consequences, for it led to erroneous conclusions in investigations, metallurgical and otherwise, which required, for the interpretation of the data obtained, the application of such a principle as Le Chatelier's theorem. If the members of the Committee still doubted that solid steel was more dense than liquid steel, it was incumbent on them to state the evidence on which their objections were based, for in the present state of knowledge the onus of proof rested with those who argued the contrary.

The Committee replied later as follows:

The discussion upon the Report has been carefully considered by the Committee, and they feel gratified with its reception, and particularly with the general acceptance of the representative nature of the data. They feel that the results of the work extending over the last two years have established the nature and the degree of heterogeneity which may reasonably be expected in carbon steel ingots produced under good conditions, and also the effect of increasing mass upon those features. This was necessary before the work could be extended further.

During the discussion, exception was taken to Section IV., which was an attempt on the part of the Committee to focus the various views which might be advanced in explanation of the phenomena studied. The Committee would, however, point out that the diversity of opinion amongst those who took part in the discussion was at least as great as amongst themselves. This is useful, and was perhaps to be expected, since, in preparing Section IV. the Committee exhaustively examined the deductions of other and previous investigators.

It is not proposed to attempt to reply in much detail to all the points which have been raised, since that would, in large measure, simply involve a repetition of the Report. Numerous questions were, however, raised which are of much interest.

The Committee appreciate Mr. Saniter's opening remarks, and his general concurrence with the facts contained in the Report. His

suggestion concerning the squeezing action of chilled crystals in producing the intermediate segregation zone is one of those explanations concerning which there is no unanimity. It is, however, intended that this aspect shall be further considered by the Committee. Mr. Saniter's suggestion, based on figures in the Report, that sulphur and manganese do not segregate together, must have serious consideration. It raises important questions regarding the formation and solubility of manganese sulphide, and is one of the matters which must be cleared up by direct experiment.

Sir Robert Hadfield's comments are also appreciated, and the Committee concur that the speed and conditions of freezing are important factors in the nature and orientation of heterogeneity.

With Sir William Ellis's remarks they are in general agreement, and they would particularly like to have the opportunity of examining the effect of the Harmet process on heterogeneity. They hope that some ingot may be found upon which experiments can be conducted. They feel with Sir William Ellis that as regards the elimination of heterogeneity, the difficulty lies in the fact that, as the mass increases, the control of the natural laws producing differential freezing constitutes a very difficult problem.

The Committee also value the details of the several failures which Mr. Stromeyer put forward in the discussion.

Turning to Mr. Brearley's contribution, they are gratified to find that he is quite in accord as to the data presented. They will consider seriously his comments relative to the V-segregate. As regards his suggestion as to the cause of the upward trend of the columnar crystals, they feel that his argument is quite logical.

With regard to Dr. Moore's contribution, the Committee share with Dr. Hatfield his views relative to the exaggerated pictorial effect of segregation produced when sulphur printing is employed. Such a method is, however, fully recommended by the Committee, providing that it is appreciated that the method does produce an intensified indication. The Committee are particularly glad to know that Dr. Moore considers the Report an unbiased record. They would point out to Dr. Rosenhain that the Report was *not* put forward as propaganda for inducing engineers to modify their apparently unreasonable requirements. The Report is simply a record of an investigation undertaken to determine the nature and extent of heterogeneity which is prevalent in steel ingots produced under good conditions. The facts disclosed are worthy of very serious consideration by the engineering world, and the Committee feel that engineers will be wise to bear them in mind. Dr. Rosenhain states that what is really required is a knowledge of the equilibria of the alloys of iron, and also a more complete knowledge of the physical properties of such alloys at high temperatures. The Committee are entirely in agreement with him, and trust that the Metallurgical Department of the National Physical Laboratory will obtain and publish such information for their future guidance.

Professor Desch's valuable critical commentary has received the Committee's very serious consideration, and with regard to ingot No. 9 the suggested micro-examination will be carried out. The Committee feel, however, that Professor Desch is inclined to consider several points as established which, in reality, are not so. For instance, when speaking of the varying distances between the liquidus and solidus, which are fundamental to a proper study of the phenomena under consideration, it should be borne in mind that, even as regards the simple binary alloy iron and carbon, it cannot really be said that the distance between the liquidus and solidus is quantitatively established. In no ternary system is it established, and this emphasises one of the great difficulties confronting the Committee, namely, the paucity of physico-chemical data. Professor Desch's remarks also would rather suggest under-cooling in the case of steels, and while this is a very interesting suggestion, it is felt that the evidence is by no means definite. It is also particularly gratifying to some members of the Committee to find that Professor Desch accepts the theory of the separated crystals falling to the bottom of the ingot. Other members of the Committee do not think that Professor Desch is justified in so completely accepting this view, and feel that it is necessary to await further evidence. All the members of the Committee appreciate the trouble to which he has gone with a view to determining mathematically the relative density of iron when it changes from the liquid to the solid state. They must, however, insist that although two methods are employed which give substantial agreement in the results, yet in both cases assumptions are made as a basis for the mathematical treatment which are not unassailable. Particularly do they think that the formula employed should not be used for extrapolation. With regard to Professor Desch's observations on the Soret effect, there is disagreement within the Committee, but certain of the members are content to be able to leave their case in the hands of Dr. Smith and Professor Benedicks, whose comments in the discussion are worthy of the most careful consideration. Professor Desch's views on the viscosity of molten steel are of great interest, but the Committee feel that they would like an experimental demonstration as to their accuracy.

They are interested in Mr. Turner's observations, and are able to inform him that whether the steel be poured into the mould from the top or the bottom, the distribution of the segregate is materially the same.

Dr. S. W. Smith's remarks are very interesting, particularly as they concern more or less analogous effects in non-ferrous castings. "Liquation," whether it is identical with the Ludwig-Soret effect or not, does, in a number of cases, appear to occur with steel ingots as it does with non-ferrous ones. The difficulty is to distinguish this from other and possibly more powerful effects.

Dr. Hanson's contribution involves terminology. If the scale of "segregation" is so small that a microscope is necessary to distinguish

and separate areas of varying compositions, is it "segregation"? If so, then the term must be taken to embrace the separation of various phases under all circumstances, and includes in the extreme every tiny particle of impurity previously in solution.

Dr. Benedicks' remarks again deal with the Ludwig-Soret effect, and oppose those of Dr. Desch; his view of the action of silicon and manganese in reducing the effect is very interesting. On the question of the factors influencing the depth of columnar crystals, Dr. Benedicks argues that the heat capacity of the mould is the chief factor. Experience in the works would indicate that the "temperature" of the steel is of at least equal importance.

They appreciate the comments from Mr. E. A. Atkins. Generally speaking, they are in accord with the remarks of Mr. Hibbard, but they would point out that it is very difficult to make a distinction between those elements which are alloyed with iron and those which are combined, since those which alloy also form chemical compounds.

Mr. Cosmo Johns' contribution, coming from one with a long experience in the manufacture of the largest size of ingots, is of particular value. They are pleased that he should emphasise the need for considerable experience in interpreting sulphur prints. Mr. Cosmo Johns discussed at some length the question of the nature of the volume change when steel passes from the liquid to the solid state, and the Committee regret that they are unable in that particular matter to add to their comments in the Report. As already stated, it is quite clear that, from a deductive point of view Professor Desch has added considerably to the discussion, but it is hoped that direct experimental determinations may be forthcoming in the future to settle the matter definitely.

Iron and Steel Institute.

A NOTE ON THE DISTRIBUTION OF SILICATES IN STEEL INGOTS.*

By J. H. S. DICKENSON, F.Inst.P. (Sheffield).

1. Introduction.

Stead,[1] in 1905, separated elongated particles of slaggy matter from steel forgings, identified them as essentially manganese silicate, and made some suggestions regarding both the origin and prevention of an obviously undesirable constituent.

Since then the source, nature, and effect of entangled slaggy matter has been dealt with by, among many other workers, Stead, Law,[2] Rosenhain,[3] Hibbard,[4] Pacher,[5] Mars,[6] McCance,[7] and Giolitti,[8] while an excellent chapter on "Slag Occlusions" is included in "Ingots and Ingot Moulds," by A. W. and H. Brearley. In all this published information, however, remarkably little attention is devoted to the distribution of entangled slaggy matter in steel ingots.

So long ago as 1905, Howorth [9] produced evidence to show that test-pieces taken from the bottom ends of large gun forgings tended to contain more slaggy matter than those coming from the ends forged from the upper parts of ingots. McCance [7] referred to the influence of convection currents in determining the ultimate arrangements of non-metallic matter in the frozen steel, but the author is not aware of any published investigation to ascertain whether the influences determining the final distribution lead to substantially similar results in all ingots, or whether the arrangement of the slaggy matter varies from ingot to ingot and is purely a matter of chance.

Commencing soon after Stead described his simple method for the separation of slaggy matter, and as a direct consequence of that most valuable piece of work, a large number of ingots, varying in size from a few cwts. up to about 60 tons, have been systematically examined in the Vickers Metallurgical Research

* Received February 18, 1926.

Laboratories, the percentage of entangled slaggy matter being estimated at various points by a modification of Stead's method of separation, applied quantitatively.

As the results appear to indicate quite conclusively that ingots small and large, and made not only by the author's firm but by some other British makers of large ingots, show a definite similarity in the distribution of the slaggy particles, it is considered that the following paper may be of interest.

It is not intended to discuss in any detail either the origin or the effect of the entangled particles, beyond making a few preliminary observations of a general character.

All the ingots dealt with here have been made either by the acid open-hearth or the Héroult electric processes; in both cases the steel was deoxidised in the furnace with the object of producing perfectly sound ingots suitable for the manufacture of forgings required to comply with exacting specifications and rigorous inspection.

It is now agreed that every ladle of steel "deoxidised" by the addition of silicon and manganese, or indeed any other deoxidiser, contains a greater or lesser, but always appreciable amount of the results of the reaction between the dissolved ferrous oxide and the "additions," in the form of exceeding small globules of a silicate, most of which are too small to rise to the surface in the time available. Undoubtedly some separation by rising to the surface does occur, not only in the furnace and during the waiting time in the ladle, but also in the mould if the ingot be at all large.

Against this must be set the absorption of oxygen by the stream of metal during teeming, which produces fresh ferrous oxide to react with dissolved free silicon and manganese. The only steel-making process free from this disadvantage is the making of "dead-melted" crucible steel, which is quickly teemed in a few moments into the mould.

There are, of course, other sources of non-metallic or slaggy impurity than the inevitable deoxidation products; refractory material from the "lander," the ladle lining, the nozzle, and so on, is certainly apt to be carried, in a very fine state of sub-division, into the mould. So also is furnace slag, churned into the current of steel as it issues from the tap-hole. The evidence goes to show, however, that although such extraneous slaggy

matter does sometimes lead to trouble, and should always be avoided as far as possible by cleanly methods and careful selection of refractory materials, the main and predominant source of the entangled non-metallic matter, which is manifested in the form of inferior transverse test results, " slag specks," and " sandy patches," is the result of a reaction which cannot be avoided if sound steel free from " blowholes " is to be produced.[7, 10]

Although the large slaggy enclosures, easily visible to the naked eye and sometimes appearing in groups or clusters covering a considerable area of a machined forging, almost always have the same origin as the finely divided non-metallic matter finely distributed throughout the whole mass of an ingot, they cannot be regarded in quite the same way as inevitable, if undesired, constituents of a normal steel ingot.

In the casting of a large ingot some of the silicate globules coalesce into relatively large masses which more readily escape to the surface and are floated upwards as the steel rises in the mould. This is all to the good, but unfortunately the currents set up by the stream descending from the ladle tend to carry these patches of " cream " towards the mould wall, where some may stick. If this happens, and the steel rises over the anchored slaggy matter, some of it may break away and attempt to regain the surface, but it will probably be trapped in the solidifying chill wall, to be discovered at a later stage when the forging is being machined. Such defects, of which every maker of large ingots in the world has painful experience, may sometimes occur, as a matter of chance or accident, anywhere in the outer portions of a large ingot, but it is not these accidental and occasional enclosures, but the normal scattered and finally divided matter, with which this paper is primarily concerned.

2. Method Used for the Estimation of Non-Metallic Impurities.

Various methods have been suggested for the estimation of slaggy matter in steel or wrought iron. Eggertz dissolved drillings in iodine, in an ice-cooled beaker; Berzelius used copper-ammonium chloride; while Wehl suggested an electrolytic method, using weak hydrochloric acid. None of these methods appears

to be either satisfactory or necessary for the separation of the silicates existing in a steel ingot, and certainly no process demanding the use of drillings or small shavings is acceptable, as any separated slaggy residue consists of shattered particles unsuitable for subsequent microscopic examination.[11]

The method first tried by the author was based on that of Stead, and has since been developed by Mr. Huxley, A.R.S.M., F.I.C., Chief Chemist of Messrs. Vickers, Sheffield, the following being the details :

In order to obtain a sufficient residue, the sample to be dissolved should weigh about 75 grammes, but it may be conveniently sawn into a number of pieces.

When broken test-pieces are to be examined the sample should be cut from the undeformed end.

Introduce the weighed sample into a 1000 cubic centimetre R.P. flask and add 750 cubic centimetres of 10 per cent. HNO_3. Fit into the neck of the flask a pure rubber bung, through which pass two glass tubes, a long one reaching to the bottom of the flask and a short one just passing the bung, in the same way as a wash bottle. Both tubes are bent outwards at right angles above the bung, so that if a number of estimations are to be made concurrently, as is convenient, the flasks may be connected in series. Connect the end short tube to a suction pump, draw a brisk current of air through the system for two full days, and disconnect. The continuous agitation of the liquid contents of the flask by the air current greatly hastens the solution of the steel. Transfer the solution to a 1000 cubic centimetre beaker, add 70 cubic centimetres of concentrated HNO_3, cover the beaker and allow to settle. Meanwhile fill up the flask with 10 per cent. HNO_3 and again pass air for two more days, during which time the solid matter in the beaker will have completely settled out. Gently syphon off the clear supernatant liquid from the beaker without disturbing the residue. Add the fresh solution from the flask together with 70 cubic centimetres of concentrated HNO_3, and again allow to settle for two days. If the sample in the flask is not completely dissolved after four complete days a fresh supply of 10 per cent. HNO_3 will have to be added, and so the process is continued until all the residue is in the beaker along with the last acid from the flask.

Allow to settle completely, and syphon off the clear liquid, leaving about 50 cubic centimetres of liquid above the residue in the beaker. Raise this to boiling point, add 20 cubic centimetres of strong potassium permanganate solution (50 grammes per litre), and digest just short of boiling for thirty minutes. Clear with hydrogen peroxide and allow to settle, when the carbonaceous residue will have disappeared.

Gently decant through a paper filter. Add 100 cubic centimetres of 5 per cent. hydrochloric acid to the residue in the beaker, boil for ten minutes, allow to settle, and again decant through the same filter. Wash the filter with water and add 50 cubic centimetres of 10 per cent. sodium hydrate to the residue. Boil again for ten minutes, allow to settle, and again decant through the same filter. Repeat the treatment with sodium hydrate. This removes the last traces of gelatinous silicic acid derived from the silicon in solid solution in the steel. Add 100 cubic centimetres of 5 per cent. hydrochloric acid, filter completely, washing out the residue, and washing the paper with water. Ignite gently, and weigh the residue.

Microscopic examination of the residues thus obtained shows that the globules of slaggy matter separated from ingots, and the elongated particles from forged or rolled sections, have not been affected by the weak cold acid used in dissolving the steel. The particles, particularly the globules from ingots, show a smooth shining surface with no trace of pitting or roughening; on the contrary, they usually shine like glass beads or pearls.

There seems to be no reason to suppose that any appreciable solution of slaggy matter, existing in the form of a fused silicate, does take place, and the principal criticism of the separation seems to be the possibility of loss during decantation. However, care and ample time for settling will avoid even this mischance, and the residue can be seen to lie, as a quiet and unaffected whitish dust, on the bottom of the beaker as decantation proceeds.

Figs. 9 and 10 (Plate XXII.) are photomicrographs, both at 100 diameters, of typical residues separated from a 10-ton carbon steel ingot and a large nickel-chrome steel forging respectively.

Table I. gives a few selected analyses of similar residues separated by the above process, along with those of two samples of slaggy matter scraped, or chipped, from "sandy patches"

appearing on the exterior rough machined surfaces of large forgings, and two analyses of large particles of slaggy matter detached from pipe cavities.

TABLE I.

		SiO_2. Per Cent.	MnO. Per Cent.	FeO. Per Cent.	Al_2O_3. Per Cent.
Residue obtained by complete solution of normal samples	(1) Large nickel-chrome steel ingot	49·0	41·5	1·9	9·5
	(2) Large carbon steel forging	40·5	28·8	18·0	11·5
	(3) Large nickel-chrome steel forging	53·7	40·1	4·7	trace
	(4) Large nickel-chrome steel ingot	55·0	33·0	14·5	1·6
	(5) 15-cwt. nickel-chrome steel ingot	72·0	22·5	3·9	1·1
	(6) 12-ton nickel-chrome steel ingot	54·5	40·9	4·1	...
From pipe cavities	(7) Carbon steel	55·5	32·5	12·0	...
	(8) Carbon steel	41·3	20·0	16·3	14·5
Scraped from external "slag streaks"	(9) Nickel-chrome steel forging	48·5	35·2	16·2	trace
	(10) Carbon steel forging	41·9	46·8	4·8	6·5

The general similarity in the analyses of Table I. strongly suggests that the three forms of slaggy enclosures came from the same source, the silicate globules suspended in the fluid steel. The difference seems to be that whereas the matter forming large external "slag streaks" had separated during casting, before the mould had filled, and had been entangled as already described, the glassy particles within the pipe cavity had worked out at a later stage when the upper surface had frozen over, and any slaggy matter which succeeded in reaching the fluid surface must come to rest in the shrinkage cavity forming within the head.

3. THE DISTRIBUTION OF SILICATES IN TWO TYPICAL INGOTS.

This section deals with the distribution of the scattered particles which remain, still finely divided, within the frozen steel. The two ingots to be discussed were both made of acid

open-hearth nickel-chromium steel. Both were cast into octagon chill moulds, wider at the upper end, and provided with refractory linings for the feeder-head. One was relatively small, weighing 15 cwts., with a diameter of 15 inches at the top of the body, and was bottom-cast in a group. The other was much larger, weighing 12 tons, with an upper end diameter of 36 inches, and was, of course, top-cast.

The analyses were as follows :

	No. 1. 15-Inch Octagonal Chill Mould. Per Cent.	No. 2. 36-Inch Octagonal Chill Mould. Per Cent.
Carbon	0·13	0·21
Silicon	0·22	0·13
Manganese	0·44	0·60
Sulphur	0·037	0·026
Phosphorus	0·023	0·027
Nickel	3·650	3·76
Chromium	0·64	0·40

When cold, both ingots were longitudinally half-sectioned ; a complete slice ¾-inch thick including head and body was cut from the smaller, but in the case of the larger the head was first parted off just below the shoulder, and the body was cut in two to provide a half-section exactly across the central axis.

After smooth planing and scraping, both ingot sections were etched with 5 per cent. nitric acid and photographed, with the results shown by Figs. 7 and 8 (Plates XX. and XXI.). As any attempt to dry a large etched ingot section always causes unsightly smears and discolorations, besides greatly lessening the brilliance and beauty of the etching pattern, these sections were etched horizontally, the camera being mounted overhead and pointing vertically downwards. After the last application of acid the surface was kept flooded with water from a hose, of course in constant motion, until the exposure was completed.

Despite the very considerable difference in the mass of the two ingots, the principal structural features are very similar, and accord with the internal arrangements of most of the nickel-chromium steel ingots which the author has examined.

There are the same external columnar walls, built up of chill crystals having a decided upward inclination, a light-etching central pyramid of free crystals, resting on the bottom floor of chill crystals and extending upwards well towards the upper end

of the body, and an annular zone of free crystals which etch differently from those of the lower pyramid.

It may be noted, in passing, that the annular zone in the larger ingot does not show the clearly defined ghosts which are usually to be found in medium-carbon steel ingots of similar mass. Probably because the carbon content is usually lower, but possibly to some extent because of the presence of chromium, it is found that large nickel-chromium ingots are less liable to show marked segregation than similar ingots of carbon steel or nickel steel made to comply with the usual specifications for heavy special forgings.

Samples for estimation of silicates and general chemical analysis were then removed from a number of points on each ingot section, those from the larger ingot being trepanned out.

All the analyses obtained from the smaller 15-inch octagonal ingot are given in Table II., the source of each sample being indicated in Figs. 1 and 2, which set out, in position on the ingot section, the sulphur and "silicate" results.

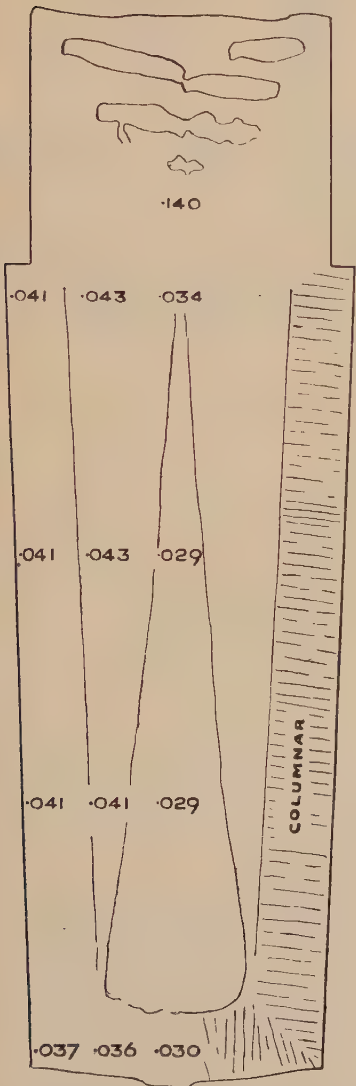
TABLE II.

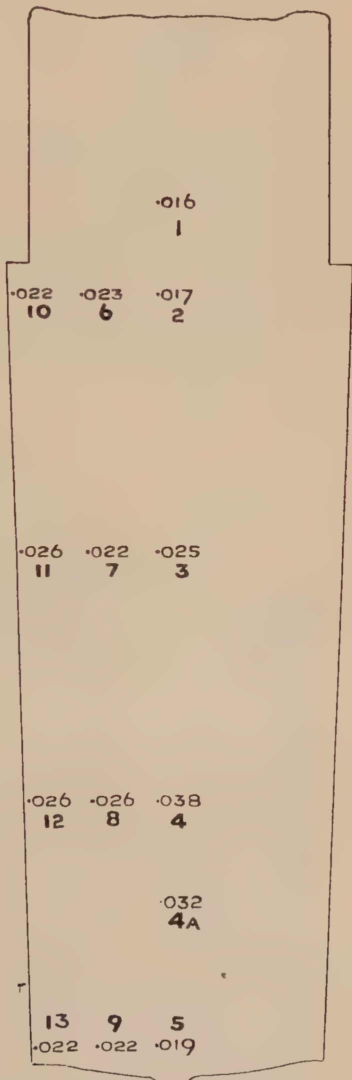
Position in Ingot.	Carbon. Per Cent.	Silicon. Per Cent.	Manganese. Per Cent.	Sulphur. Per Cent.	Phosphorus. Per Cent.	Nickel. Per Cent.	Chromium. Per Cent.	Slaggy Matter. Per Cent.
1	0·20	0·25	0·51	0·140	0·060	3·81	0·68	0·016
2	0·13	0·21	0·44	0·034	0·023	3·66	0·65	0·017
3	0·14	0·21	0·44	0·029	0·023	3·64	0·65	0·025
4	0·12	0·21	0·43	0·029	0·022	3·60	0·63	0·038
4A	...	...	...	...	...	...	...	0·032
5	0·13	0·21	0·46	0·030	0·024	3·63	0·65	0·019
6	0·13	0·21	0·45	0·043	0·025	3·68	0·65	0·023
7	0·13	0·21	0·45	0·043	0·026	3·69	0·63	0·022
8	0·13	0·22	0·44	0·041	0·024	3·69	0·65	0·026
9	0·13	0·22	0·45	0·036	0·024	3·60	0·63	0·022
10	0·13	0·22	0·44	0·041	0·023	3·65	0·65	0·022
11	0·13	0·22	0·44	0·041	0·023	3·65	0·65	0·026
12	0·13	0·22	0·45	0·041	0·025	3·65	0·65	0·026
13	0·13	0·22	0·44	0·037	0·024	3·65	0·64	0·022

These show some significant variations, but with the exception of phosphorus, which shows less variation than the sulphur, the differences in the other elements, of course within the ingot body, are not greater than the limits of permissible analytical error.

It is unnecessary to tabulate similarly all the results obtained

from the thirty samples removed at various points across the 12-ton ingot half-section. The four following elements showed





15-cwt. (15-inch Octagonal) Ingot.

FIG. 1.—Sulphur Results.

FIG. 2.—" Silicate " Results.

very little variation, and only the highest and lowest results will be given:

	Minimum. Per Cent.	Maximum. Per Cent.
Silicon	0·13	0·14
Manganese	0·58	0·62
Nickel	3·73	3·84
Chromium	0·36	0·42

The carbon and sulphur results are set out in position on the ingot section in Fig. 3, while the "silicate" results are similarly dealt with in Fig. 4.

The phosphorus variations closely follow those of the sulphur, the differences between the highest and lowest results of each of the segregating elements, and of the "silicates," being conveniently contrasted, along with the corresponding figures within the body of the small ingot, in Table III. below:

TABLE III.

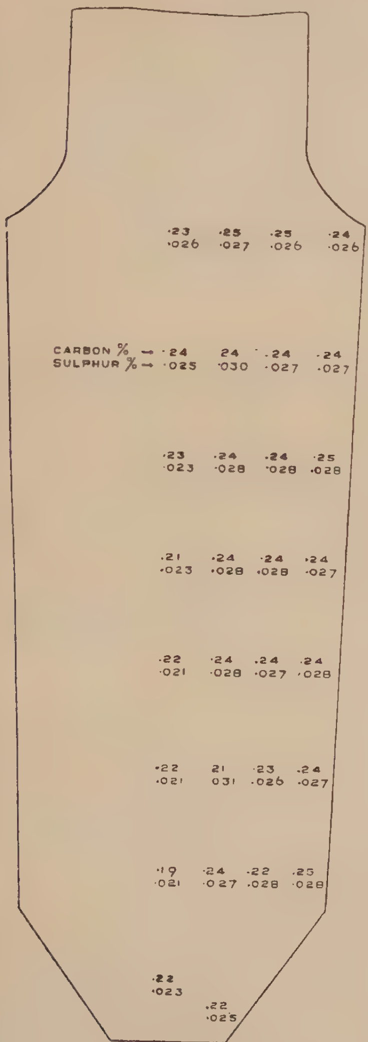
	Large (12-ton) Ingot.			Small (15-cwt.) Ingot.		
	Min.	Max.	Ratio of Min. to Max.	Min.	Max.	Ratio of Min. to Max.
	Per Cent.	Per Cent.		Per Cent.	Per Cent.	
Carbon	0·19	0·25	1 to 1·31	0·12	0·14	1 to 1·17
Sulphur	0·021	0·031	1 ,, 1·48	0·029	0·043	1 ,, 1·48
Phosphorus	0·022	0·028	1 ,, 1·27	0·022	0·026	1 ,, 1·17
"Silicates"	0·004	0·036	1 ,, 9·00	0·017	0·038	1 ,, 2·23

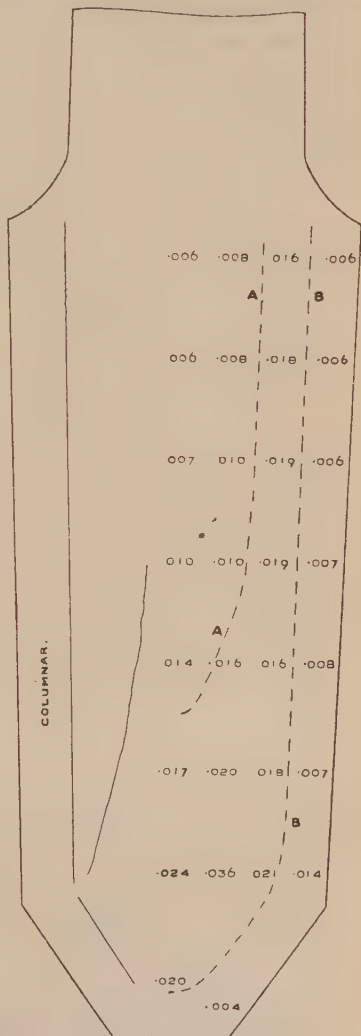
Although the larger ingot shows much greater variation in the silicate results, the mean content of the smaller ingot is greater at 0·024 per cent. than that of the 12-ton ingot at 0·013 per cent., an unexpected but very interesting fact.

The two ingots agree in showing the highest silicate content at or near the central axis near the bottom end, and within the lower part of the central pyramid of free crystals. In both ingots, samples taken from the columnar walls everywhere show a fairly uniform distribution of silicate, except one result near the bottom of the ingot, which is probably due to the trapping of some separated slaggy matter.

In both ingots, also, the amount of silicate steadily falls on moving up the central axis from the region of maximum

content near the bottom. In the case of the small ingot it





12-ton (36-inch Octagonal) Ingot.

FIG. 3.—Sulphur and Carbon Results. FIG. 4.—" Silicate " Results.

actually falls to a minimum at the place of maximum sulphur, phosphorus, and carbon segregation in the head just below the

pipe cavity. No doubt the same result would have been reached in the larger ingot had the head been sectioned.

There is, however, one very striking feature shown by the 12-ton ingot, not to be observed in the smaller, this being the perfectly definite indication of an annular zone, in the upper half of the ingot, where the silicates are present in greater quantities than in the columnar wall on the outside, or in the core within.

This is clearly brought out by the zoning on the right side of Fig. 4, where that part of the ingot containing over 0·015 per cent. silicates is enclosed by the lines AA, BB. On the left of the ingot section the main structural divisions revealed by etching are lightly indicated.

The significance of these observations will be briefly discussed later, but clearly they prove, considered as a whole, that there has been an ordered arrangement of the silicate particles in each of these two ingots, which has led to a striking similarity in the distribution. This is the more noteworthy in view of the considerable disparity in size, and of the fact that the smaller ingot was bottom-cast while the large one was top-cast.

It may be noted at this point that after the preparation of micro-slides the residues from each of these two ingots were combined to provide samples for analysis, with the results given as Nos. 5 and 6 in Table I.

4. The Distribution of Silicates in Large Ingots.

That the distribution in large ingots of the order of 50 tons weight follows a similar plan, quite distinct from that of the ordinary segregation of carbon, sulphur, and phosphorus, is proved by some additional evidence in Table IV.

With the exception of No. 1, a 10-ton carbon steel ingot which was sectioned for special investigation, the large ingots in this table were all made into hollow forgings, and the silicate estimations were necessarily made on samples removed from trepanned cores * and across the end surfaces of the top-end discards.

The approximate relative position in the ingot from which each sample came is shown by Fig. 5, but as the spacing was not

* Except No. 3, which was trepanned before cogging.

always quite the same, it must be understood that each result given is that of the sample nearest to the indicated position. In no case was the displacement between the actual and assumed

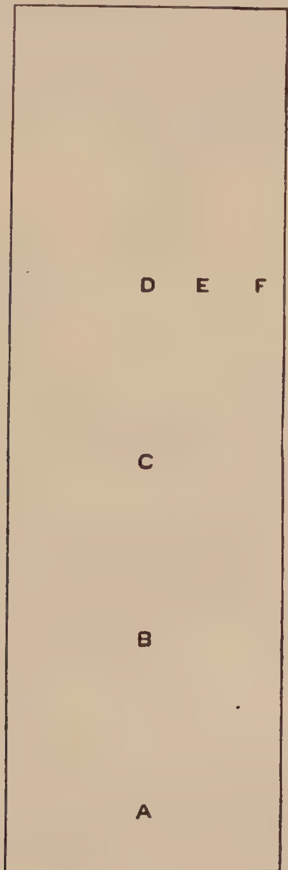


Fig. 5.

position sufficient to affect in the least the validity of the comparison. The interest of this table is increased by the addition, when available, of carbon results taken from the same sample as the "silicate" results with which they are coupled in each case.

Both the individual results and the average figures set out at the foot of the table show very convincingly that the migration

of segregates and silicates has proceeded on different lines, and, just as in the case of the two ingots in the previous section, the amount of silicate is higher near the bottom of the ingot than near the top. So far as the results go it is indicated that ordinary segregation has proceeded on normal lines, but in none of these examples is there any evidence of the upper annular zone of higher silicate content shown in Fig. 4, and the amount on the line of the top-end discard parting cut decreases in each case from the columnar outer zone to the central axis.

TABLE IV.

No.	Details of Ingot.				Position in Ingot (see Fig. 5).					
	Class of Steel.	Mean Diam.	Weight.		A.	B.	C.	D.	E.	F.
		Inches.	Tons.		Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	Héroult carbon	36	10	Silicates	0·030	0·009	0·003	0·002	0·002	0·002
				Carbon	0·22	0·22	0·29	0·34	0·34	0·28
2	Acid O.-H. Ni-Cr	52	53	Silicates	0·046	0·011	0·008	0·005	0·005	0·017
3	Acid O.-H. nickel	50	50	Silicates	0·068	0·007	0·005	...	0·005	0·007
				Carbon	0·27	0·37	0·48	...	0·44	0·38
4	Acid O.-H. Ni-Cr	52	44	Silicates	0·040	0·010	0·007	0·004	0·006	0·009
				Carbon	0·25	0·23	0·23	0·28	0·28	0·25
5	Acid O.-H. Ni-Cr	52	44	Silicates	0·090	0·010	0·006	0·008	0·012	0·025
	Averages of silicate results			. .	0·055	0·009	0·006	0·005	0·006	0·012
	Averages of carbon results			. .	0·25	0·27	0·33	...	0·35	0·30

Fig. 6 shows a number of carbon and "silicate" results obtained at various positions in the bottom-end discard of No. 3 ingot of Table IV. Each pair of determinations was made at the same position on one side of the central axis, but the results are divided for convenience.

The figures are entirely consistent, and prove that the silicate content of the first frozen skin at the bottom end is low, being much the same as that of the outer skin at the upper end, position F in Table IV., but that there is a continuous rise upwards and inwards from the side of the well to the central point ("A" of Fig. 5), where the maximum amount of 0·068 per cent. is reached. The carbon shows a corresponding fall from the outer skin, reaching

a minimum at the same place. It is, of course, quite possible that somewhat higher and lower contents of silicate and carbon, respectively, might have been found a little higher on the central

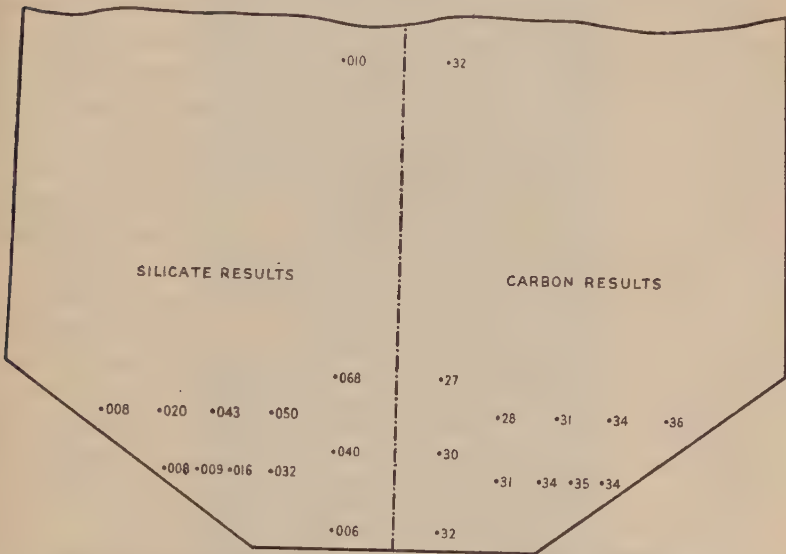


Fig. 6.—Bottom End of 50-ton Nickel Steel Ingot (No. 3 of Table IV.).

axis had additional samples been removed from the lower end of the trepanned-out core.

It may be added that other large ingots have given much the same indications, and that one of the large ingots of Table IV. was made by another British maker of large ingots.

5. Microscopic Appearance of Separated Silicates.

The silicates separated both from ingots and forgings, but particularly the former, provide microscopic objects of great beauty. Unfortunately they are extremely difficult to photograph satisfactorily, chiefly because the particles vary so much in diameter that many are necessarily out of focus.

Although the silicate residue obtained from any one ingot sample is composed of particles of greatly differing size, there

appears to be a marked similarity in the general appearance and colour of the residues from different parts of the same ingot, which suggests a corresponding uniformity of composition. The author hopes later, by the solution of quite large samples cut from different parts of an ingot, to obtain sufficiently large residues for this point to be settled by analysis. There is, however, no doubt that the residues from the lower central part of an ingot, the region of high silicate content, are largely composed of globules of greater size than those found elsewhere. Thus Figs. 11 and 12 (Plate XXIII.) are photomicrographs at 100 diameters of residues from the 50-ton ingot No. 3 of Table IV., these having been removed from the positions A and C, respectively, in Fig. 5. Figs. 13 and 14 (Plate XXIV.), at the same magnification but differently illuminated, are from the 15-cwt. ingot at, respectively, the positions No. 4 and No. 1 in Fig. 2. These photographs also indicate that the globules tend to become larger with increasing size of ingot, but this will scarcely be news to any maker or user of large steel ingots. Away from the lower central portion, the residues do not appear to vary much in the mean size, or range of sizes, of their constituent particles, but comparisons are not easily made, and the author cannot be very definite on this point.

The residues from the larger ingots are usually made up of opaque, yellowish pear-like particles, such as those in Figs. 11 and 12, but for some reason the residues from every part of the 15-cwt. ingot were chiefly composed of transparent particles looking like clear glass beads. This may be due to the fact, as shown by analysis No. 5 of Table I., obtained from the combined residues of this ingot, that the percentage of SiO_2 was high in this case.

Examination at 100 diameters shows the larger particles in most ingot residues, comprising the greater part of the total weight, to be globular or pear-shaped, but higher powers sometimes reveal much more complicated shapes among the small particles; a few examples are given in the four photomicrographs at 500 diameters. Figs. 16, 17, and 18 (Plate XXV.) are all from the lower part of the 15-cwt. ingot (position 4 in Fig. 2), and they show, besides small globular particles, other forms having the appearance of bent and branched glassy rods with bulbous ends. These, like the remarkable combinations of welded globules in Fig. 15 (Plate XXV.), from position 1 in the head of the

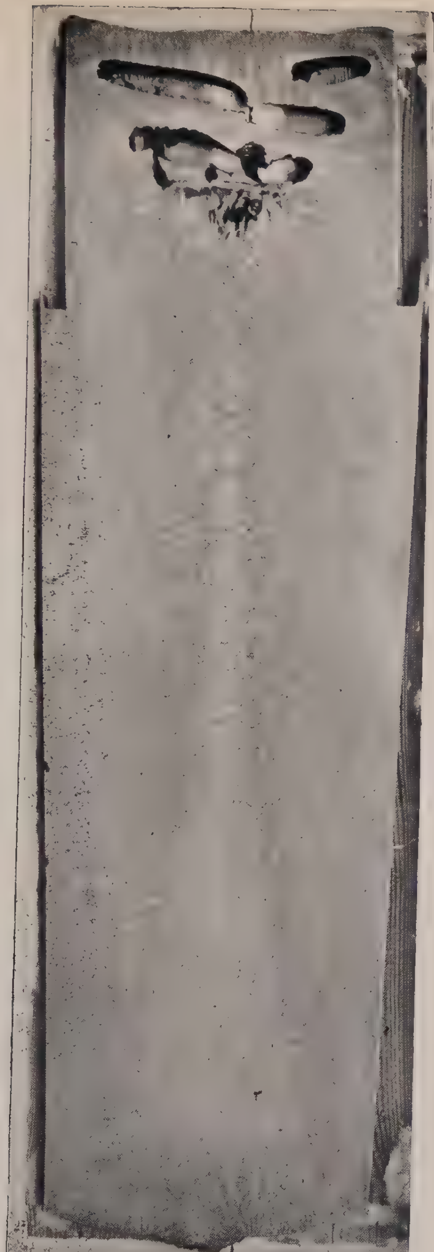


FIG. 7.—Photograph of etched longitudinal half-section of 15-cwt. ingot of nickel-chromium steel.

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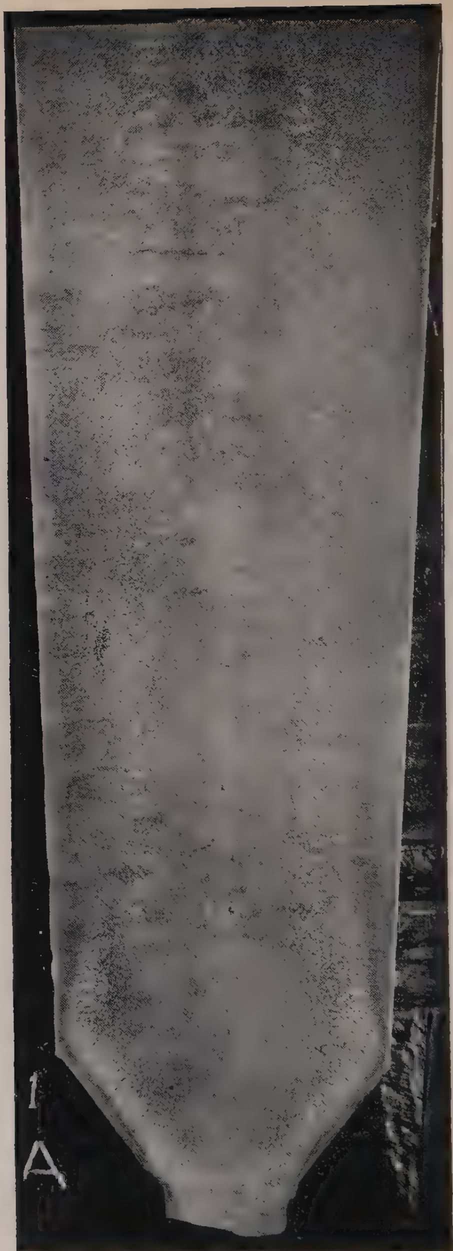

FIG. 8.—Photograph of etched longitudinal half-section without head, of 12- ton ingot of nickel-chromium steel.

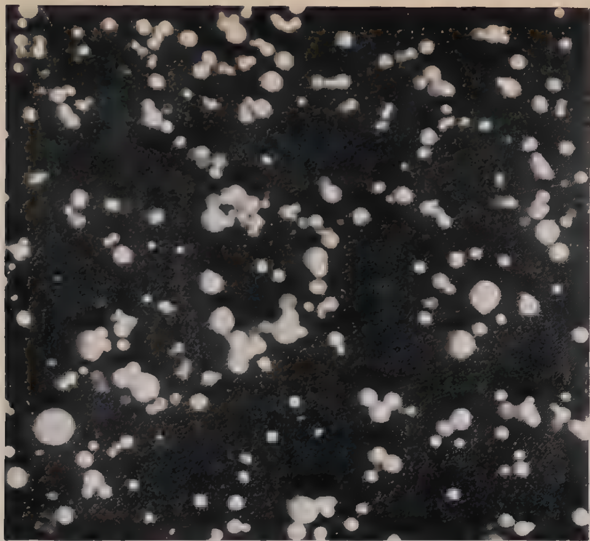

FIG. 9.—Silicate globules separated from 10-ton carbon steel ingot. ×100

FIG. 10.—Silicate particles separated from large nickel-chromium steel forging. ×100.

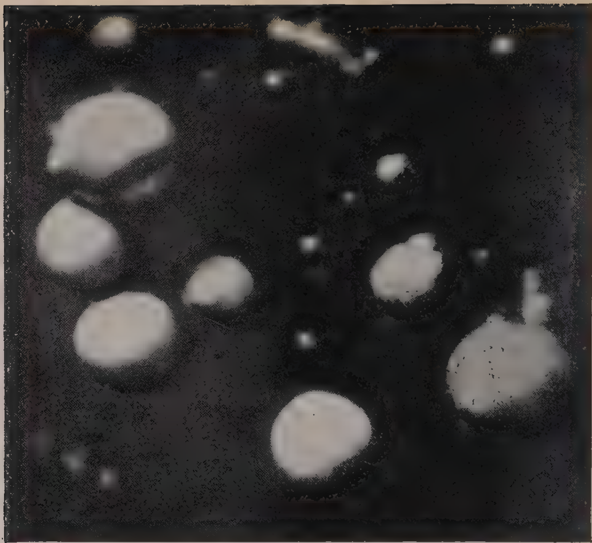

FIG. 11.—Silicate globules from position *A* of 50-ton ingot No. 3 of Table IV. ×100.

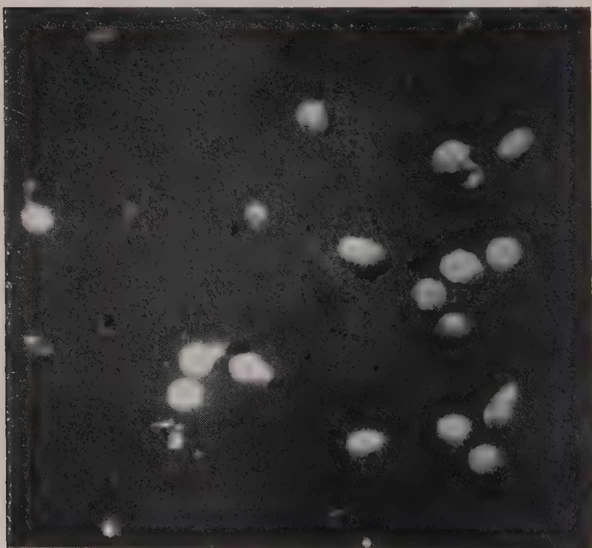

FIG. 12.—Silicate globules from position *C* of 50-ton ingot No. 3 of Table IV. ×100.

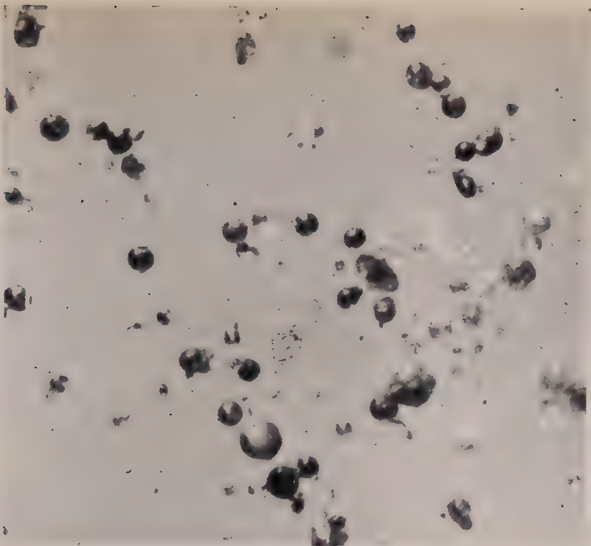

FIG. 13.—Silicate globules from position 4 of 15-cwt. ingot. ×100.

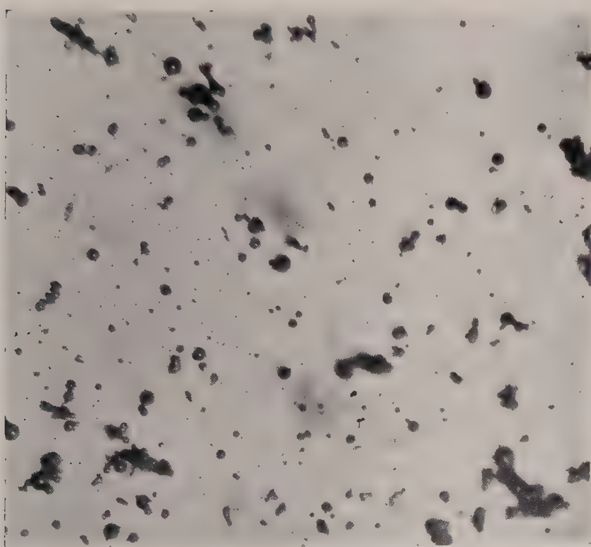

FIG. 14.—Silicate globules from position 1 of 15-cwt. ingot. ×100.

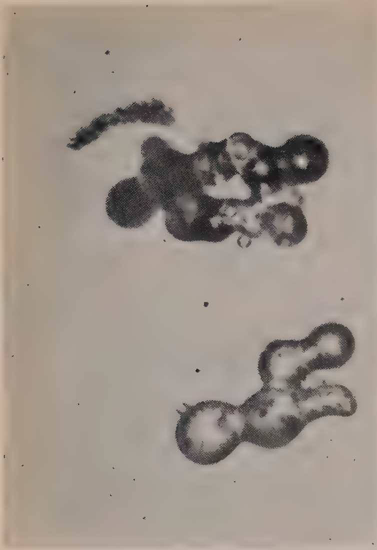

FIG. 15.—× 500.

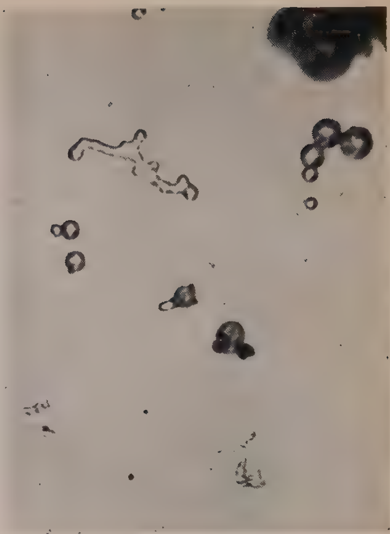

FIG. 16.—× 500.

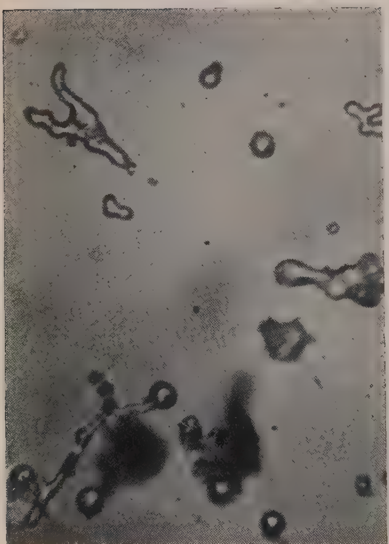

FIG. 17.—× 500.

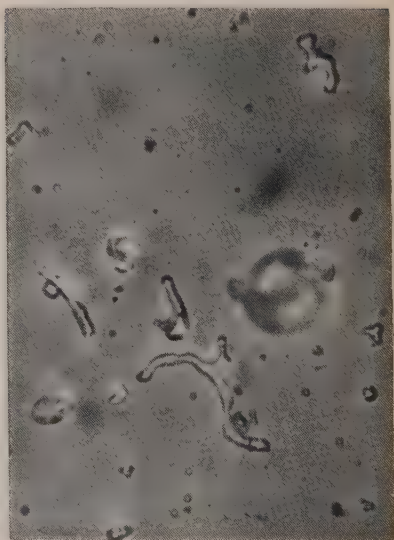

FIG. 18.—× 500.

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same ingot, strongly suggest that they have been shaped by the growing metallic crystallites.

The range of size of the silicate globules in these selected residues is possibly sufficiently indicated by the photographs, but it may be noted that the very small globules, attached to the larger linked globules in Fig. 15, are about 0·0003 centimetre in diameter, while the large globules in the same residue are about 0·0025 centimetre in diameter. The largest globules found in this 15-cwt. ingot, from the lower central region, are about 0·005 centimetre in diameter, and may be compared with the 0·015 centimetre diameter globules of the corresponding lower-end residues of the 50-ton ingot (Fig. 11).

6. Conclusion.

As the Sub-Committee reporting on the heterogeneity of steel ingots, on which the author has the pleasure to serve, includes in the Report placed before this meeting a section devoted to the theoretical consideration of the phenomena involved in the solidification of a steel ingot, it is not considered desirable to discuss this matter at any length in the present paper. At the same time, it is felt that the quite distinct difference between the migration of the silicate particles within a freezing steel ingot as compared with segregation of carbon, sulphur, and phosphorus must be explained before any account of the process of solidification within the walls of a chill mould can be accepted.

The evidence now presented, and which was considered to be outside the scope of the Sub-Committee's Report, amounts, in brief, to this—that in each of a number of ingots, all made of carefully killed or deoxidised steel for the manufacture of special forgings, the percentage of slaggy matter in the form of small globular silicate particles rose to a maximum in the central lower part, precisely where carbon, sulphur, and phosphorus were each reduced to a minimum by segregation.

This applied to quite small as well as to very large ingots, to ingots of carbon, nickel, and nickel-chromium steels, to top-cast and bottom-cast ingots, and, it should be added, to large ingots made by other firms. It was further found that in this region, which lay a little above the floor of columnar crystals,

and within the pyramid of light-etching free crystals erected upon this floor, the silicates were not only greater in amount, but the separated residues included a considerable proportion of globules which were larger than those normally to be found in any other part of the ingot.

As the globules of slaggy matter suspended in the fluid steel should escape more readily as their size increases, the presence of such globules near the central axis, and a little above the bottom, must be due to their being carried to, or held in, that position by the solidifying steel. It was supposed at one time that this congregation of large slaggy particles near the bottom end might be connected with the stream of metal from the ladle, which probably produces a far-reaching downward current even when a large mould is nearly full; but the fact that a small bottom-cast ingot showed the same effect as larger ingots, not quite so clearly, but still unmistakably, disposes of this, at any rate as the sole explanation.

Some years ago Stead (12) suggested that during the growth of the chill walls a circulating current is set up by the segregate rising within the advancing columnar chill walls, with a corresponding movement downwards along the central axis. Certainly the appearance of the ghost lines within the annular zone strongly suggests such a movement, while the central pyramid, which in one form or another is such a characteristic feature of "killed steel" ingot sections, equally points to the continuous deposition of heavy pure crystallites on the rising fluid floor.

If such a current were set in motion, there would be a tendency for crystallites, forming in the downward current as it cooled near the bottom, to attach themselves to particles of slaggy matter, which would become attached to the floor and there remain. According to this view, the impurer mother liquor would remain fluid for some time longer, so that any rejected segregate would be turned into the rising current then moving upwards towards the head, which might or might not be reached.

The upper annular zone within the lines AA and BB in Fig. 4 does, in fact, indicate the presence of silicate particles which have escaped entanglement in the lower part of the ingot, but which appear to have been trapped together with rising segregate in their journey upwards along the advancing crystalline faces.

It is, however, very difficult to conceive of such a circulatory current, and a more probable explanation is that, just as large globules of rejected segregate forming within the chill wall move upwards by a process of displacement, often leaving behind them intercepted trails to form "ghosts," so also there is centrally a continuous downward movement of purer crystallites, again by displacement. Such a rain of heavy, purer crystallites upon the narrowing and rising solid floor would tend to intercept and carry down some of the larger coalesced particles of slaggy matter, and would also, of course, build a pyramid. Any particles which escaped this sweeping action would, of course, tend to move upwards and come to rest in the pipe cavity, thus leaving the upper central portion of the ingot free of all but the smaller, and, therefore, more slowly rising globules.

The probability that there is, in fact, such a downward fall of crystallites in the central space was confirmed some years ago in a discussion with Mr. H. Brearley, who based his opinion on indications given by purposely "bled" ingots.

It may be suggested that the relative freedom of the columnar skin from entangled slaggy matter, except such as has reached the surface during casting and has then been accidentally trapped, is due to the pushing inwards of the larger coalesced globules in the steel by the growing chill crystals. Such globules would, of course, tend to rise with the segregate, with an excellent chance of reaching the pipe cavity. Indeed, in most cases it is probable that the annular zone, where segregate in the form of ghosts is plentiful, is fairly free of entangled slaggy matter, but the case of the ingot shown in Fig. 4 shows quite clearly that this does not always occur.

The relatively high mean silicate content of the bottom-cast 15-cwt. ingot, as compared with the larger ingots, and the lesser degree of variation in the amounts determined at different points, may be explained by supposing that the much more rapid solidification of the steel through to the centre has prevented much coalescence, movement, or escape to the surface of the globules before they were frozen in.

Much more might be said on this subject, but under the present circumstances the author is content to put forward the evidence, which might be greatly supplemented and confirmed, if necessary,

for general information. There are, of course, some very important practical implications, but it is not proposed to enter into these at the present time.

It may, however, be pointed out that there is much more work to be done in this direction before it will be possible to make comparisons of ingots or forgings on the basis of quantitative silicate determinations. The author's results fortunately include a few cases of other makers' ingots, but these were of a similar class of steel, and it is probable that the similar examination of ordinary mild steel ingots, both acid and basic, might lead to some very surprising results, both as regards the nature, amount, and distribution of entangled slaggy matter.

Finally, the author desires to express his thanks to his friend and colleague, Mr. Huxley, and various assistants in the chemical laboratory, particularly Mr. F. W. Gray, for the large number of analyses carried out by them; to Mr. G. E. Howarth for the photomicrography; and to the Directors of Messrs. Vickers, Ltd., for permission to communicate these selections from investigations on steel ingots carried out, over a long period, in the Vickers Research Laboratories.

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DISCUSSION.

Dr. A. McCance (Uddingston, N.B.) said that on first reading the paper he had been particularly struck by the two photographs on Plate XXII., the top one showing the globular nature of the silicate inclusions in the ingot form, and the lower one showing how those globular inclusions had been elongated in the process of forging. With regard to the composition of those inclusions, he desired to ask if the author were quite certain that the method of attack with increasing strengths of nitric acid did not dissolve out some of the higher oxide inclusions? From the analyses of many inclusions which he (Dr. McCance) had come across, he had always found that the silica in the inclusion was lower than the figure which the author gave, the most general figure being about 30 to 40 per cent. He had not yet met with any inclusions with so high a content of silica as 70 per cent., and he wondered whether the author had made any check experiments to ensure that his method of attack had not exerted some solvent action on certain of the silicates, so leaving only the particular type which the author had found. Would the author also give the sulphur analyses of those inclusions? He personally believed that in no case did pure manganese sulphide exist in any steel ingot or in any steel mass, but that the sulphide was mixed with the silicate, and that the silicate largely predominated.

The segregation with the higher content of silicate inclusions which the author had found in the lower part of the ingot was very striking. He thought the author's suggestion that some downward stream of metal was forcing those inclusions down to the bottom was the probable one. If the rate at which small particles of that nature were rising in the steel were calculated, assuming a known viscosity, say, for the steel, it was found to be extremely slow and, for ordinary-sized particles, in the nature of a few inches only per minute, so that a very violent downward current would not be required to carry those particles to the bottom and prevent their rising to the top. As to the cause of that downward stream, it was rather difficult to find what appeared to be any adequate explanation, but he would like to make the following suggestion. When an ingot was solidifying, the first crystals deposited from the liquid steel were lower in carbon than the liquid from which they were deposited, and that left the liquid much enriched in carbon. He believed that, owing to lack of diffusion, that enriched part was in the form of a thin sheet next to the solidified shell of the ingot. That sheet went on growing until, when it got to a certain thickness, owing to the excess of carbon which it contained and its lower density, it rose suddenly, and those apparent spasmodic movements were the cause, not only of the segregate of non-metallic particles at the bottom

of the ingot, but also to a large extent of those spasmodic line segregates which were found in the ingot.

Dr. W. Rosenhain, F.R.S. (National Physical Laboratory), remarked that a point which had occurred to him in reading the paper (Dr. McCance had also referred to it), was that in observing the non-metallic enclosures in ordinary steel articles—forgings or rolled material—the sulphides and silicate enclosures were generally found associated. They would be found lying in the same bands in the banded structure of the steel. Apparently, according to Mr. Dickenson, the sulphur segregation was quite a different thing from the arrangement of the silicates in the ingot, and it was a little difficult to see how, if that were so, the apparent association of the two kinds of enclosures in wrought material came about. The question of the manner in which those silicate particles were retained at the bottom of the ingot was an interesting one. He did not think that the theory of a rain of crystals pushing them down, or holding them down, was very feasible. If Dr. Desch's figures were taken as correct—and he thought they were probably not very far from the facts—there was a difference of density between those solidified particles and the surrounding liquid of about 4 per cent. When it was realised that a difference of density of 4 per cent. meant only a very slight tendency to fall (at any rate until the particles were very large), it would be seen that there was hardly time for very much downward movement to occur from that slight cause; and when those falling crystals were entangled with particles of comparable size of a density of something like $2\frac{1}{2}$ or 3, like the silicate particles, the average density would be so much less than that of the surrounding steel that the whole lot together ought to rise unless they were held by actual freezing. He was only saying that in order to show that it could not be definitely said that there was a rain of crystals or that those particles ought to rise.

What was really the origin of those silicates? He thought Dr. Stead's work showed that fairly clearly. At any rate, in part they were due to the presence of oxygen in the steel. There was silicon; obviously there were iron and manganese, and when there was oxygen as well, there were the necessary materials for the production of silicates. The oxygen might be partly in the steel already; in other words, the silicates themselves might have been formed in the furnace or in the ladle. To some extent they were bound to be increased by the oxidation at the surface of the jet, which inevitably occurred when the stream of molten steel fell down into the ingot mould. It fell a good deal further when the bottom of the ingot was being poured than when the top was, consequently a greater formation of silicates occurred at that stage. Perhaps that was why those lower portions of the ingot were richer in silicates than the top; in that case it was not a question of segregation, but of gradual formation during the pouring of the ingot. Exactly where they would be found as the result

of such a process as he was imagining it was difficult to say; it depended so much on the relative rate of pouring of the steel, and the rate at which it solidified. If the rate of solidification of the bottom part were fairly rapid compared with the rest, then the retention there of the silicate which was formed when that part of the ingot was being filled could be understood. He would point out that the bottom part of the ingot did undergo perhaps rather more rapid solidification than the upper part, for the reason that when the ingot mould was a third or a quarter full, the walls higher up had already become very seriously heated by conduction, whereas the walls of the mould at the time of commencing to fill the ingot were not heated in that way. That would explain the floor of columnar crystals; but even beyond that point the abstraction of heat was not lessened by the conductivity of heat along the mould walls from below upwards, which must affect the solidification of the upper portions.

He did not desire to stress those points too much; he was putting them forward as suggestions which did not seem to have been considered, but did require consideration in trying to explain the very remarkable fact of those larger silicate particles being found in greater abundance in the lower part of the ingot. It would account also for the fact—if his suggestion of the oxidation of the jet during teeming were correct—that there was no corresponding sulphur segregation in that part of the ingot, because, of course, there would be no increase of the sulphide globules from such a cause.

The author's paper was extraordinarily interesting, and he hoped that he would pursue the subject further, because he had almost unique opportunities for doing so.

Dr. W. H. Hatfield (Sheffield) said that investigators would probably use and apply the author's process for isolating and investigating the nature of inclusions pretty generally; in fact, since the publication of the paper, his own laboratory had commenced work on similar lines, and no doubt most laboratories would be doing the same.

With regard to the results which the author obtained by using the process, the matter was different, and he was very much in sympathy with a great deal that Dr. Rosenhain had said. He would refer the author to the Report which he had taken such a part in preparing. In Tables IV. and V. of the "Heterogeneity of Steel Ingots Report" were given the silicon and sulphur contents for the different portions of the ingots. It was rather obvious that if, as was suggested by the author, the crystallites formed throughout the molten steel and carried down with them silicates which otherwise would not occupy a position towards the bottom of the ingot, it was fair to assume that those same crystallites would carry down some sulphides, and that if that portion of the steel were richer in silicates it would also be richer in sulphides. It was therefore of great interest to compare the two tables. If silicates had been carried down it was obvious that the silicon content would

be higher in that area. If the positions A and B of the Committee's examples were compared (A being on the outside of the ingot and B being in the position of high-silicate content, as indicated by the author), it would be seen that in Example 1, $A = 21$, $B = 20$, and in the next examples 52, 51; 23, 23; 15, 14; 21, 20; 13, 17; 18, 20; 27, 27; 16, 16; 13, 11. On silicon alone it would appear, to his mind, that while the author was no doubt perfectly correct in stating that according to the ingots of his firm's own manufacture which he had examined the silicates were high in the position mentioned, yet it was fairly clear from the figures of the Committee that the same did not hold for ingots of all manufacture; and that, of course, was the main point he wished to make. Reference to Table V. of the Heterogeneity Report revealed the astonishing fact that the sulphur did not increase where the silicates were high; it was much less. He knew that the author would balance the two actions, which the Committee had pointed out in their treatise on the subject, but the fact remained that if, as suggested by Dr. Rosenhain, in the early stages of teeming there were a fair amount of oxidation taking place, which would involve the production of silica and oxide of manganese, there one would have the explanation. If, on the other hand, ingots were teemed under different conditions, with which the author would be quite familiar, it was quite conceivable that the silicates would not be higher there.

There was another point. The author asked how did one particular silicate inclusion come to be deformed? He would suggest that the formation of the crystals, when the silicate was still plastic, would be a quite sufficient explanation.

In conclusion, he would like to make one observation. It was perfectly clear that, contrary to the author's claim, his evidence did not constitute a convincing argument in favour of the shower of falling crystals. That was a fundamental point which the members of the Committee must have settled sooner or later.

Mr. H. Brearley (Member of Council) said there was one note in the paper to which some reference ought to be made. He could assure the author on behalf of steel-makers generally that he need not apologise for the admission that the firm with which he was associated made ingots containing slag globules. There was nothing to be ashamed of in that. There might be something to be ashamed of, and it would certainly be a sign of ignorance, if any person pretended, either directly or inferentially, that his firm made ingots or could make ingots that did not contain slag globules. The author gave a limited assent to the suggestion that free crystals moved downwards during the solidification of a steel ingot—not every steel ingot, but in the solidification of a steel ingot which had been cast under certain conditions. He did not know whether that suggestion had originated with himself, but it was certainly made in the book his brother and he had written about steel ingots and ingot moulds. He had not altered his mind

about the falling of free crystals during the solidification of those types of ingots which had been cast under conditions such that chilled crystals and free crystals composed the solidified ingot itself. It was difficult to bring direct proof of that point, but the most suggestive evidence was that which could be got from making wax ingots. He was aware that experience with wax ingots did not necessarily apply to steel. If, however, a suitable series of stearine wax ingots were made and upset after appropriate periods, it would be clearly seen that in stearine wax ingots the free crystals which formed fell to the bottom. In the "Heterogeneity of Steel Ingots Report" the surprising suggestion was made that solid steel might not be heavier than liquid steel. Unless solid steel was specifically heavier than liquid steel, free crystals could not possibly fall to the bottom. It seemed to him that anyone who had cast a steel ingot and noticed that during the solidification it piped—that was to say, it shrunk and occupied less volume than it did in its liquid condition—must be convinced that in the solid state steel was heavier than it was in the liquid state.

Dr. Desch had given a shrinkage figure of about 4 per cent. It was many years since he had made any observations on the point, but the figure he had obtained had not been as high as that given by Dr. Desch. He had made an attempt with an ingot itself to measure the total amount of shrinkage and contraction, which were, of course, the two volume changes occurring between the liquid condition on the one hand and the solid and cold ingot on the other. The total volume change which he had found at that time had been about 3·7 per cent., of which about half was due to contraction.

There was one other suggestion he would like to make. If mild steels were machined into bars, or anything else, and the machined and ground, or ground and polished, surfaces were carefully observed, here and there the appearance of slag streaks, which the author had separated as undistorted globules, would be seen. When steel ingots were made under something like comparable conditions the number of slag streaks of a size visible to the naked eye was found to be greater in mild steels than in harder steels. In a steel, for example, containing about 0·2 per cent. carbon, and using that rough measure of the occurrence of the slag streak—its visibility to the naked eye—about ten times as many slag streaks would be found as in a steel containing about 1 per cent. carbon.

He would like to ask the author whether there was anything in the observations he had made on the occurrence of slag in ingots which would enable him to throw any light on that enormous difference.

Mr. E. A. Atkins (Warrington) asked the author whether, in the course of his investigations, he had come across any cases of silicate formations that were crystalline in shape. Personally, he had met with several. He had been able to separate the non-metallic inclusions

from the steel, not from the ingot. One particular case was that of a hot-rolled rod $\frac{1}{5}$ inch in diameter. He had worked on somewhat similar lines to the author's, but his object had been quite different.

In connection with the cold-working of steel, and also the cutting and screwing of steel, he had for many years observed certain definite specks in the steel which caused very serious trouble, and for a very long time he had been trying to isolate them. He had not been able to do so until last year, but he had succeeded in actually separating them by a method not unlike that employed by the author for separating the silicates. Those specks had been confirmed not only in a very small diameter—in, say, a $\frac{3}{16}$-inch diameter hot-rolled rod—but also in a 2-inch by 2-inch billet, and also in pit samples taken repeatedly. The specks were extremely small; they could only be seen on the steel by very careful polishing. Those specks caused serious trouble in connection with the cold-working of the steel. They did not appear to break off or to break away; they were present in the original ingot, and they persisted in the billet and in subsequent drawing operations, and were finally still present in a $\frac{1}{16}$-inch diameter wire.

In conclusion, he desired to ask one question. He noticed in the analysis of the silicates that the amount of alumina varied in the different samples from 1·1 up to 14·5 per cent. Could the author state whether aluminium was used for deoxidising his steels?

The PRESIDENT said that Mr. Atkins had referred to the absence of elongation in the specks. In order to bring it home to the members, he might say that Mr. Atkins' sample of wire was ten times its original length. Yet the little specks obviously gave no signs of elongation at all, being approximately spherical, showing that they must have retained their shape in spite of the fact that the whole of the steel had been drawn cold to ten times its original length.

Mr. H. BREARLEY (Member of Council) asked Mr. Atkins whether the steel wire to which he had referred was mild steel wire, and whether he knew if any aluminium had been used in the ingot mould or in the ladle. If aluminium had been used in the ingot mould, he did not think Mr. Atkins need go far to seek for the cause of his small and beautifully shaped crystals.

Mr. E. A. ATKINS replied that he did not want to refer to the matter at any great length, because he was preparing a paper which would deal with the whole question. In cases where aluminium was added to the deoxidiser the specks were obtained in proportion to the amount of aluminium added, but they also appeared in other cases where aluminium was not added.

Mr. E. H. SANITER (Member of Council) said he wished to draw attention to the variation of the FeO in many of the inclusions. He

did not know whether there were any possibility of perhaps scrapings of steel having got in and having thus made it vary, but he had himself found that when steel was made solid with silicon that the iron oxide was generally very low. He had also been able to pick out of the top ends of ingots pieces as big as pigeons' eggs, which had largely consisted of manganese oxide and iron oxide and very little silica indeed, but that was a steel with no silicon in it.

Dr. Hatfield had referred to the author's suggestion that the fall of the crystallites brought the silicates down to the bottom or kept them down there, and had said that the same ought to happen to the sulphides; but Dr. Hatfield had yet to prove that there was an insoluble sulphide in the steel at that stage of the proceedings. He thought Dr. Hatfield had given a very good proof that it was not there, if there were anything in the author's theory.

Mr. J. H. WHITELEY (Stockton-on-Tees) remarked that the first thing which had struck him on reading the paper had been the extraordinarily small amount of silicates which were actually present in steel. Very few of the results given in the paper were above 0·03 per cent. That fully confirmed his own observations. He had frequently had samples of steel to examine, which appeared, under the microscope, to contain very large amounts of silicates; in some cases he would have said 0·3 or 0·4 per cent., but when he had come to test them by a method similar to that adopted by the author he had found only about 0·02 per cent. He remembered discussing the matter with the late Dr. Stead, who had suggested that other compounds besides silicates might occur as non-metallic inclusions, his suggestion being that, in the case of basic steel, ferrate of lime might be present. He (Mr. Whiteley) was inclined to that opinion also. In one particular case that he remembered, a piece of plate made of basic steel clearly contained excessive amounts of non-metallic impurities, yet, on testing for silicates, he could not find any. Although the inclusions appeared to be silicates, they were soluble in very weak acids. He desired to suggest to the author that he should not overlook that point in his investigations. Ferrous oxide, for instance, was exceedingly soluble in very weak hydrochloric acid, and he believed the lower oxide of manganese was also very soluble; analytical tests as to the amount of non-metallic impurities really present in the steel might therefore be misleading.

He had been much interested in the fact that some of the silicates were shown to be transparent. That such was the case he had frequently suspected, because on examination under a high power the particles could often be seen to be translucent. For that reason he had come to the conclusion that many of the silicates were glassy, although he had not isolated and examined them as the author had done. The question of the composition of the silicates was very important. Silicates varied considerably in their behaviour during the

rolling or forging operation. Some of them seemed to be rigid, and refused to be flattened out. Others flowed easily and formed very fine strings. These latter, he believed, were much more dangerous.

In regard to the position of the silicates in the ingot, the author had said that they occurred to the greatest extent in the lower half of the ingot. That might be the case with sound steel such as the author had been testing, but his own experience went to show that if the steel were not sound—that is, if it were of the rising type—the highest concentration of silicates was generally to be found just under the skin, where it often gave rise to surface defects in the steel. He thought there was still room for a good deal of research on the question as to where the silicates really did concentrate in ingots.

CORRESPONDENCE.

Mr. T. P. Colclough (Rotherham) wrote that there was no doubt that the paper, containing the results of prolonged and careful work, would exert a stimulating effect on similar researches among other workers. Since all samples had been treated in the same way, there seemed to be little doubt as to the value of the figures obtained for a *comparative* study of the distribution of silicates in steel ingots. There might, however, be some doubt as to whether the method adopted yielded accurate figures for the *total* silicate present in the steel. Exception must be taken to the author's claim that "there seems to be no reason to suppose that any appreciable solution of slaggy matter . . . does take place."

The following tests indicated that some further experimental work was necessary before a strictly accurate method could be established for the determination of those silicates.

Solvent.	10 per Cent. HNO_3.	10 per Cent. H_2SO_4.
Residue.	0·0147 per Cent.	0·0296 per Cent.
	Analysis.	
	Per Cent.	Per Cent.
SiO_2	48·9	41·4
FeO	18·9	17·2
MnO	32·1	41·4

No aluminium was used in the making of the steel.

Two samples of approximately 100 grammes weight were cut from a piece of badly laminated steel. The samples were polished on all faces, washed with alcohol to remove grease, &c., and weighed. They

were then dissolved in cold 10 per cent. solutions of nitric acid and sulphuric acid respectively. The solutions were decanted, and the residues were thoroughly washed and dried at 120° C. They were then digested with concentrated nitric acid to remove carbonaceous material, extracted with water and acid, and filtered through tared papers. The residues were weighed and analysed, with the results shown in the table on p. 204.

It would be seen that while the residues were approximately of the same composition in the two cases, yet that obtained by solution in sulphuric acid was almost exactly double that from the nitric acid treatment. That would seem to indicate that some solution of the slaggy matter did take place in the nitric acid. Further investigations of this matter were in hand.

The distribution of the silicates in the ingot, as shown by the author's figures, was certainly surprising, and far from what would be expected, but, failing evidence to the contrary, it must be accepted as correct in view of the number of ingots examined. Further, if the data in the paper were accepted as typical, they furnished a striking testimonial to the advances made by steel-makers in the removal of those deleterious constituents of steel. Compared with figures given by Campbell some years ago, the silicates found by the author represented less than one-tenth of the amount determined in American steel some thirty years ago.

Mr. E. H. SANITER (Member of Council) wrote that on examining Table I. he found that the analyses given therein totalled up to the following figures: (1) 101·9 per cent., (2) 98·8 per cent., (3) 98·5 per cent., (4) 104·5 per cent., (5) 99·5 per cent., (6) 99·5 per cent., (7) 100·0 per cent., (8) 92·1 per cent., (9) 99·9 per cent., (10) 100·0 per cent. Two added up to considerably over 100 per cent., and required some explanation. Those under 100 per cent. might be due to some constituent not being given in the table. In No. 7, which added up to 100 per cent., no Al_2O_3 was given, although all the other carbon steels showed considerable percentages of that compound. The writer had an analysis made of the slag from the pipe of a 6-ton ingot of the following approximate composition: Carbon 0·35, silicon 0·12, manganese 0·7 per cent.; the result was as follows: SiO_2 53·5, FeO 19·3, MnO 16·4, Al_2O_3 11·4 per cent.; total 100·6 per cent. That also confirmed the presence of Al_2O_3 in carbon steel inclusions.

The considerable differences in the percentages of SiO_2, MnO, and FeO in the inclusions from the various steels given in the table might be due to differences in the contents of silicon and manganese in the steels, or to differences in the condition of the bath when tapped; it would be interesting, in this connection, if the author could give the analyses of all the steels.

It seemed extraordinary that the inclusions from the nickel-chromium steels should contain no chromium oxide.

Mr. T. M. Service (Glasgow) wrote that, like the author, he had had many opportunities of examining non-metallic inclusions in steel, and also of deciding if any one position in an ingot were likely to contain more of those inclusions than another. It was necessary, before coming to a decision, to examine the conditions under which inclusions were formed in the molten bath, and to decide whether the inclusions formed there were the same as those given in Table I. by Mr. Dickenson. When samples were drawn from the molten bath in the dead-melted condition and cooled rapidly in water, micro-examination showed the existence of two types of inclusions in very small amount; one type

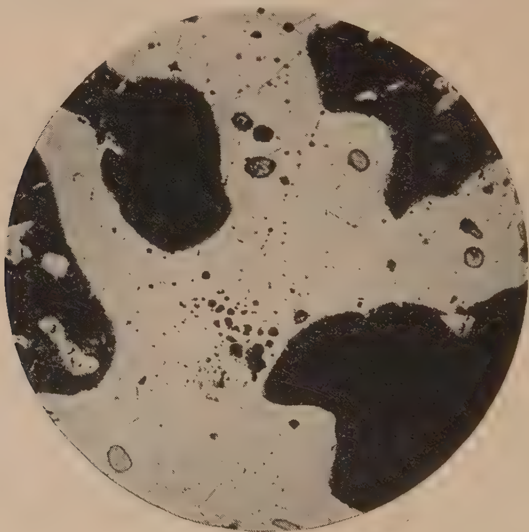

Fig. A.

had a smooth glassy appearance, evidently silica or a silicate, while the other had the well-known iron sulphide appearance. On adding to the bath deoxidising agents, such as ferro-silicon and ferro-manganese, and allowing them to remain there for at least two hours, micro-examination of freshly drawn and rapidly water-cooled samples still showed two types of inclusions. The first appeared to be silica with traces of iron and manganese; the second was iron sulphide. Silica sand was generally used round the stopper in ladles, and was in contact with the molten metal for at least fifteen minutes, or longer. If the first metal run from the ladle, which contained a large percentage of that sand, were caught and a section examined, the inclusions in it were similar in appearance to the glassy inclusions in deoxidised steel.

From the examination of a great many samples, he had come to the

conclusion that the inclusions due to reactions in the furnace were: (1) Silica containing traces of MnO and FeO. (2) If the metal were cooled very quickly, such as was done by drawing a molten sample and cooling in water, FeS still existed, but if the metal were slowly cooled, MnS, or MnS containing FeS, resulted. The FeS appeared to remain in solution as such until the metal had cooled almost to the point of solidification, when it reacted with the manganese to form those sulphides which existed as isolated spots in the dark-etching bands seen on the sulphur print. The micrograph, Fig. A, showed MnS inclusions in the dark-etching portion shown by the sulphur print (magnification 100).

The inclusions given in Table I. by Mr. Dickenson did not agree with the two types mentioned above. His samples contained varying quantities of manganese oxide, ferrous oxide, and alumina:

	No. 1. Per Cent.	No. 3. Per Cent.	No. 4. Per Cent.
Ferrous oxide . . .	1·9	4·7	14·7
Alumina . . .	9·5	trace	1·6

During the time the metal was running from the ladle and rising in the mould, oxidation of the metal and slagging of the nozzle occurred, as a result of which a non-metallic scum formed on the surface of the metal. The following were analyses of scums from different classes of steels:

	SiO_2.	MnO.	FeO.	CaO.	Al_2O_3.	Cr_2O_3.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
No. 1 . . .	47·04	34·37	6·43	0·40	7·86	3·22
No. 2 . . .	50·16	30·55	8·83	0·50	5·43	4·82
No. 3 . . .	47·64	38·23	9·97	0·38	5·06	...

Nos. 1 and 2 were nickel-chromium steels, and No. 3 was a carbon steel.

Occasionally during the machining of forgings specks of non-metallic matter were found; they were usually called "sand" in the machine-shop. Those specks were picked out of a shaft and analysed, with the following result: SiO_2 40·80, MnO 46·5, FeO plus Al_2O_3 11·2, and CaO 1·4 per cent. The analysis of the scum and the sand agreed very well with that given in Table I. by Mr. Dickenson. If steel were cast through a nozzle on which it had little action, and if the action of the air on the stream of steel and in the mould during filling could be avoided, the formation of that scum could be almost, if not entirely, prevented.

An observer who had watched the stripping and lifting of the present type of ingots, *i.e.* with the wide end uppermost surmounted by a head kept hot by being enclosed in a casing lined with refractory material, would notice that the bottom end of the ingot up to a

certain distance was black, the temperature gradually increasing to a bright red in the top portion and head. At the commencement of teeming metal from the ladle into the mould, precautions were usually taken to prevent the sand round the stopper from entering the mould, and as the action of the metal on the pot was progressive the first metal in the mould would not contain so many inclusions as when the metal had been running for some time. Later, however, as the pot got heated and the slagging action became more intense, those inclusions would increase, and as the bottom end of the ingot, as already stated, cooled first, they were trapped. At a later stage, although the slagging action on the pot was still taking place owing to the whole system, *i.e.* mould, bottom metal, &c., having become well heated, the metal retained its fluidity longer, and consequently time was allowed for inclusions to rise to the surface.

He was of the opinion that if nozzles which did not slag during teeming could be procured, and if oxidation of the metal during teeming and filling the mould could be prevented, the greater part of the harmful inclusions could be got rid of. The remainder, which were due to the furnace reactions, were governed by physical laws not yet understood, and would only be controlled or limited as greater knowledge of those laws became available.

Mr. DICKENSON wrote in reply that he had much appreciated the discussion, which had raised many interesting points for consideration. Of these the most important was probably the question, first put by Dr. McCance; he was not prepared to assert that the nitric acid used in the separation had no solvent action on any of the silicates present in the steel.

It had not been possible, as yet, to follow up the discrepancy referred to by Mr. Colclough, but he understood that the steel examined was an incompletely killed or "rising" steel, and the case might therefore be analogous to that of Mr. Whiteley. The silicates present in such steels were quite likely to be different in character from those found in "sound" ingots, as investigated by the author, and were apparently more soluble. There might even be more than one type of silicate globule in some such cases, and other methods of separation would be required, but as regards the ingots dealt with in the paper, he felt convinced that the silicate inclusions in each case were all of much the same composition, and were unaffected by the acid used. As indicated in the paper, the appearance of the separated particles, when examined microscopically, was very convincing, and the minute, delicate forms shown in Fig. 14, for example, did not appear to admit the possibility of partial solution. Further, the separated globular particles appeared to conform in range of size and general form with those observed microscopically on ordinary microsections cut from the ingots, a part of the investigation not dealt with in the paper. He considered, therefore, that the results obtained really represented the amounts of entangled

silicate present in various positions, not merely comparatively, but with a reasonable approximation to exactness.

Besides the microscopically recognisable silicate particles actually separated, there might be, and no doubt were, very minute particles of oxides, or perhaps higher oxide inclusions, even in sound and well-killed steel. Indeed, he had frequently observed in microsections from such ingots, both of carbon and alloy steels, regularly arranged specks, appearing as short, dark lines, which did not appear all over the sections, but over occasional small areas, and were obviously related to the primary crystallites. They did not show up before etching, and he had not yet determined whether they were oxides or other non-metallic inclusions, or merely, as seemed quite possible, very minute shrinkage cavities left during the final solidification in the inner spaces of the forming crystallites. In any case, even if they were inclusions (and the absence of any similar form after forging rather indicated that they were not), their total weight must be exceedingly small in comparison with the residues separated by the method described.

He considered it unnecessary to discuss at any length the fascinating question whether there was a downward movement of purer crystallites during the freezing of the lower central part of the ingot, but he might set off the views of Dr. McCance, Mr. Brearley, and Dr. Desch, who agreed that such a fall was probable, against those who dissented. He must point out, however, that the explanations advanced by Dr. Rosenhain and Mr. Service for the congregation of larger silicate particles in the lower central zone were not only quite different, but equally failed to meet the case of the bottom-cast 15-inch octagonal ingot, No. 1.

He was unable to follow the argument, advanced by Dr. Hatfield, that because falling crystallites might reasonably be assumed to carry down some sulphides as well as silicates, the portion of the ingot richer in silicates should, therefore, also be richer in sulphides. That involved the assumption that when the formation of a crystallite commenced, at some period or other the silicates and sulphides were in the same condition in relation to the liquid steel, an assumption which, as Mr. Saniter pointed out, Dr. Hatfield was not in a position to prove, and which was seemingly negatived by the result. After all, the lower central part did contain some sulphide, if less than the mean content of the ingot, just as the upper central part contained some silicate, and that was quite consonant with the explanation given by him (Mr. Dickenson).

It should be remembered that, whatever the condition of the sulphide, the formation of segregate at any point occurred subsequently to the commencement of crystallite formation, while the silicate, or most of it, was already in suspension. If, then, the purer crystallites moved downwards, and the segregate moved upwards, as it most certainly did, each would have a sweeping action on suspended silicate particles. The difference would be that any silicate particles carried downwards would be embedded in the rising solid floor, while those swept upwards by

segregate would have an excellent chance of reaching the liquid surface within the hot-head. He concurred absolutely in the suggestion that other classes of steel, differently cast, might reveal other types of silicate distribution, as well as other forms of silicate, but he would be much surprised if Dr. Hatfield did not find on examination that the sound ingots made by the two eminent firms with which he was connected failed to show the same general characteristics.

Replying to Dr. Hatfield's remarks as to the bearing of Tables IV. and V. of the "Report on Steel Ingots" on the distribution of silicates, he failed to find that the comparison of the silicon percentages provided convincing evidence on the point at issue. In most of the cases cited, the silicon percentage was of the order of 0·20 per cent., while that of silicate was certainly very much lower, so that the difference in the amount of the latter constituent at positions *A* and *B* could hardly affect appreciably the total silicon result, which it should be remembered was estimated by weighing, after ignition, not silicon, but silica. However, the point was interesting, and deserved further examination, as also did the corresponding case of manganese content.

In answer to Dr. McCance, who asked for the sulphur content of the separated inclusions, and Mr. Saniter, who had found that the analyses given in Table I. did not precisely total 100 per cent. in all cases, he would point out that the amount of separated silicate available for chemical analysis was always very small. If, for example, the steel under examination had a mean silicate content of 0·01 per cent., a sample weighing only 0·05 gramme of separated silicate globules would require the complete solution of 500 grammes of steel. The amounts available permitted the reasonably accurate determination of the principal constituents, but it had not so far been possible to analyse for constituents only present in small proportions. Under the circumstances, he considered that the analyses of Table I. totalled very well, but in the future it might be possible to separate an adequate amount for more detailed examination.

He could confirm the observations made by Mr. Brearley, that mild steels appeared usually to contain more slag streaks than high-carbon steels. He was now engaged in the examination, on the lines described in the paper, of some high-carbon steel ingots, and it was possible that the distribution of silicates in those ingots might lead to some interesting conclusions.

The information given by Mr. Atkins was of extreme interest, and he looked forward to the paper which he (Mr. Atkins) was preparing. He had found that the excessive use of aluminium, particularly in the mould, led to non-metallic inclusions of a particularly refractory and objectionable character, but he had certainly never encountered such specimens as those shown by Mr. Atkins.

In further reply to Mr. Saniter, he thought that differences in percentage of SiO_2, MnO, and FeO in the inclusions from the various steels given in Table I. were primarily due to differences in working the bath.

Certainly the variations in the FeO content were not due to scrapings of steel. In such cases the presence of Al_2O_3 in the inclusions, whether they were obtained from pipe cavities, "sandy-places," or were separated by the process described, was due to the addition of aluminium to the ladle.

Mr. Whiteley's remarks amply confirmed the view, already expressed, that an investigation of the distribution of silicate, and the character of the silicate inclusions, in other kinds of steel ingots than those examined by the author, might lead to some very important results.

Mr. Service's remarks were very interesting and valuable, but he was unable to agree that erosion of the nozzle, or oxidation during casting, which was also mentioned by Dr. Rosenhain, played such a large part in the production of non-metallic impurity as Mr. Service appeared to think. Undoubtedly both actions occurred, and if either could be avoided, the steel would be improved, but he was still of the opinion that the greater part of the non-metallic impurity present in a normal, sound ingot was due to furnace reactions.

Finally, he would suggest, in reply to the interesting point raised by Dr. Rosenhain, that the association of silicate and sulphide in the same particle was often quite accidental, and due to the contact, under influence of currents in the fluid steel, of two previously independent globules. He thought, however, that the association of silicate and sulphide particles in banded structures needed further investigation, involving the sectioning of ingots of types other than those dealt with in the present paper.

Iron and Steel Institute.

ON GHOST LINES AND THE BANDED STRUCTURE OF ROLLED AND FORGED MILD STEELS.[1]

By J. H. WHITELEY, F.I.C. (Saltburn-by-the-Sea).

A characteristic of the prominent ferrite layers or ghosts commonly found in rolled or forged mild steels is their almost complete freedom from visible carbide particles. During the period of cooling between Ar3 and Ar1, the carbon in these layers moves into the adjacent iron, clear evidence of this movement being afforded by a crowding of the pearlite at the margins. In such steels, as is well known, the pearlite is seldom uniformly distributed at any part, but tends to arrange itself in a series of bands which lie in the plane of rolling. Consequently, this banded structure may be regarded as being due to the presence of a large number of smaller ghosts which also lose their carbon as the metal cools. Stead[2] was the first to state that these ferrite layers are richer in phosphorus than the intermediate metal, and to attribute the movement of carbon to the higher phosphorus content. Although this statement was supported by many interesting experiments, it has not been universally accepted, and other explanations have been advanced. Initial crystallisation of ferrite on particles of non-metallic impurities which act as nuclei is one that is favoured by many, and it is with these two theories in particular that the present investigation is concerned.

Recently, the author[3] described some experiments made for the purpose of ascertaining definitely whether cupric reagents are capable of detecting small variations in the phosphorus content of a steel. Four pieces of electrolytic iron were phosphorised to an extent ranging from 0·02 to 0·13 per cent. by heating them at 1000° C. for a few minutes in an atmosphere of hydrogen and

[1] Received January 26, 1926.

[2] *Journal of the Society of Chemical Industry*, February 1914, vol. xxxiii. p. 173.

[3] *Journal of the Iron and Steel Institute*, 1921, No. I. p. 277.

vaporised phosphorus. Following this, they were heated in hydrogen only at about 1200° C. for two hours, in order to allow the phosphorus to diffuse through them. On analysis, the pieces were found to contain 0·023, 0·045, 0·07, and 0·13 per cent. of phosphorus respectively. A small pile was next made with a strip from each piece and alternate strips of the same iron which had received an exactly similar treatment, except that it had not been phosphorised. The pile was welded by placing it at the end of a steel tube which had the following composition: Carbon 0·03, silicon trace, phosphorus 0·006, sulphur 0·015, and manganese 0·31 per cent. The tube was then inserted in a furnace at about 1200° C. and, on reaching that temperature, hammered flat on the anvil. Oxidation was avoided by filling the tube with hydrogen. A composite sample was thus obtained containing phosphoric ghosts of known composition about $\frac{1}{400}$ inch thick.

This synthetic method of producing heterogeneity offered a convenient means of isolating and studying the effect of phosphorus on the distribution of pearlite. Some strips of the phosphorised electrolytic iron were therefore carburised in charcoal between 900° C. and 950° C. until they had a carbon content of about 0·50 per cent. They were then welded, as before, to alternate strips of the original material. To allow the carbon to diffuse uniformly through the welded pile, a section of the bar was next heated for twenty minutes at 950° C., after which it was gradually cooled to room temperature. The time taken in cooling between 900° C. and 650° C. was one hour, experiment having shown that this rate of cooling was sufficiently slow for the width of the ferrite bands in a $\frac{1}{2}$-inch plate to reach a maximum. The distribution of the pearlite in the welded area after this treatment is seen in Fig. 1 (Plate XXVI.); Fig. 2 shows the same area when lightly etched with Dufay's reagent. In the latter, the positions of the alternate phosphorised strips are made clear, and it is evident that, except in the case of the 0·13 per cent. strip, the presence of phosphorus has not caused the carbon to migrate.

It was thought that the result might be different with narrower bands. Accordingly, a section of the bar was reduced at a red heat to about one-half the thickness and given the same heat treatment. An exactly similar result was again

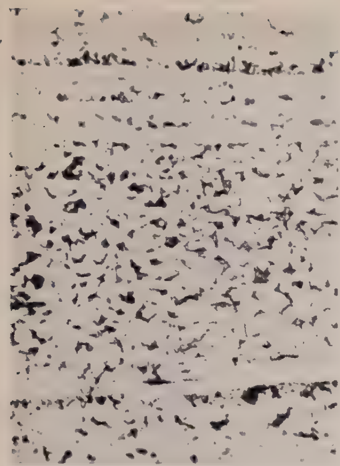

FIG. 1.—Welded pile, etched with picric acid. ×35.

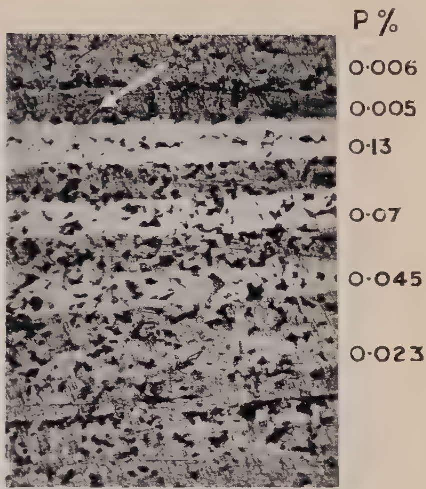

FIG. 2.—The same area as Fig. 1, etched with Dufay's reagent. ×35.

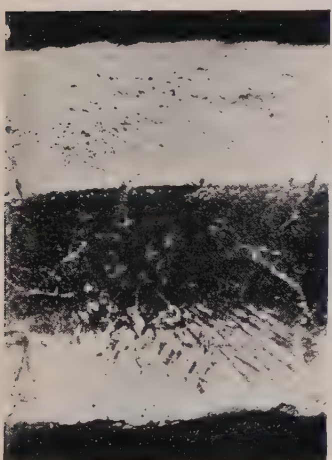

FIG. 3.—Phosphorised and carburised electrolytic sheet. ×65.

FIG. 4.—Steel plate. Phosphorus 0·004 per cent. ×35.

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FIG. 5.—Welded pile, slowly cooled. ×35.

FIG. 6.—Welded pile, quenched from 750° C. ×120.

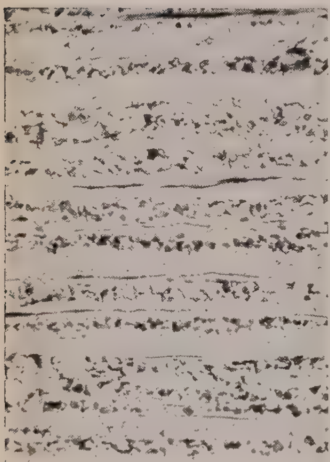

FIG. 7.—Steel plate as rolled ×90.

FIG. 8.—Steel plate, slowly cooled, after 2 hours at 1200° C. ×90.

obtained, however, the 0·13 per cent. strip being the only one to lose its carbon.

In Fig. 1 it will be noticed that while most of the carbon has left the 0·13 per cent. strip, a little has remained along its centre; an uneven distribution of the phosphorus may possibly be the reason. Strong etching indicated a somewhat lower phosphorus content at the axis, but it should be noted that, in a later experiment, slowly cooled welded strips of the pure electrolytic iron also retained some pearlite in places at their centres. In passing, a striking example of the effect of incomplete diffusion of phosphorus may here be mentioned. A piece of electrolytic iron was phosphorised up to about 1·40 per cent. and then heated in hydrogen for two hours at 1250° C. On etching, it was seen that, while there had been considerable diffusion inwards, the phosphorus content was still much higher at the surfaces than within. The piece was next case-hardened in charcoal at 900° C. and, on subsequent examination, it was found that the absorbed carbon, instead of being at the outside, had passed almost entirely to the purer centre part, as shown in Fig. 3 (Plate XXVI.).

From the results given by the welded sample, illustrated in Figs. 1 and 2, it is clear that before phosphorus can cause the migration of carbon in steel, a difference of at least 0·07 per cent. is needed between adjacent parts. To what extent ghosts and the banded structure in mild steels are due to variations in the phosphorus content alone cannot at present be stated, but it is very doubtful whether, in most cases, they are entirely the result of such heterogeneity. The following considerations will show that other factors may influence the movement of the carbon to such an extent that the effect of phosphorus may be completely outweighed.

1. The banded structure is to be seen in plates and sections containing only a trace of phosphorus. Fig. 4 (Plate XXVI.), for example, shows the distribution of pearlite in a slowly cooled steel plate which had the following analysis: Carbon 0·13, silicon 0·01, phosphorus 0·004, sulphur 0·03, and manganese 0·41 per cent. Obviously, a difference approaching 0·07 per cent. between the amounts of phosphorus in adjacent layers is, in this instance, impossible.

2. The movement of carbon may not necessarily be towards an area lower in phosphorus. In preparing a pile of strips for welding, pieces of the unphosphorised electrolytic iron, containing 0·005 per cent. of phosphorus, were always placed outside, and it was noticed repeatedly that the carbon was not retained by these outer bands; it passed into the adjacent steel of the tube, although the phosphorus content of the latter was, if anything, slightly higher than that of the iron. An instance is seen in Fig. 2, where the position of an outer layer is marked by an arrow. Here, therefore, phosphorus could not be the cause of the migration of the carbon.

This observation suggested another experiment. A pile was prepared of three strips of the electrolytic iron and two of a steel of the following analysis: Carbon 0·40, silicon 0·12, phosphorus 0·040, sulphur 0·045, and manganese 0·93 per cent. The pile was placed in a cylinder of the same steel, which was then tightly plugged and heated in a partially exhausted silica tube with a small piece of charcoal at about 1200° C. After twenty minutes at that temperature the cylinder was quickly removed, placed on the anvil and hammered down to a bar $\frac{3}{16}$ inch thick. An excellent weld was thus obtained. Two small sections were then heated at 950° C. for ten minutes; one was withdrawn and rapidly air-cooled, and the other gradually cooled to 670° C. in seventy-five minutes. Examination of the former showed that the carbon had diffused into the electrolytic bands, so that it appeared to be uniformly distributed across the welded area. The effect produced in the slowly cooled section is seen in Fig. 5 (Plate XXVII.). Separation of the carbon from the three electrolytic strips had occurred to an extent which can be judged by the marked crowding of the pearlite at the margins. As was the case with the 0·13 per cent. phosphorus strip (Fig, 2, Plate XXVI.), only a few small areas of pearlite remained in one or two places at the axes of the bands. Here again, therefore, ghosts had been formed of ferrite purer than the surrounding metal. This observation undoubtedly supports the statement of Hatfield [1] that local high phosphorus may be associated with areas richer in pearlite.

It may be argued that the removal of carbon from the electro-

[1] *Journal of the Iron and Steel Institute,* 1915, No. II. p. 122.

lytic iron is to be explained by the fact that the Ar3 point of the iron is higher than that of the adjacent steel, so that the ferrite would first appear in these parts and, during the subsequent slow cooling, would continue to deposit on these crystals rather than form new centres of growth. Howe, in fact, definitely states this to be the case as regards ghosts in steel, because the effect of phosphorus is to raise the Ar3 point.[1] This view, though attractive, is open to objection. Fig. 6 (Plate XXVII.) shows the appearance of the same weld quenched from 750° C. after it had cooled from 1000° C. to 900° C. in thirty minutes, and from 900° C. in seventy minutes. It will be seen that ferrite growth had started in the metal outside the electrolytic band before the latter had lost all its carbon. From this stage onwards, therefore, if the specimen had been further cooled, there would have been an increasing number of centres of crystallisation for the separating ferrite besides those in the electrolytic iron. Consequently, the almost complete removal of the carbon from this material would scarcely be anticipated, even though ferrite first appeared in it. Moreover, there seems to be no reason why this ferrite, instead of being confined to the bands, should not extend laterally, as it grows, into the adjacent steel if it is merely a question of the position of initial growth.

It should further be observed that these experiments lend no support to the theory originally suggested by Ziegler,[2] that non-metallic inclusions act as nuclei for the crystallisation of ferrite and so give rise to ghost formation. Whilst it must be admitted that instances of the crystallisation of ferrite round such particles are frequently to be seen, yet this explanation of ghost formation, although accepted by many metallurgists, is also open to objections, of which the two following may here be mentioned :

1. Medium carbon steels, such as rails, seldom show ferrite ghosts or a banded structure ; the ferrite exists as a network enclosing the pearlite grains. Even when considerable amounts of inclusions are present, a banded structure is not induced to form.

2. Ferrite lines in structural mild steels can be completely removed by a lengthy heating at about 1200° C. This treatment does not, of course, remove the non-metallic particles or greatly

[1] "The Metallography of Steel and Cast Iron," p. 561.
[2] *Revue de Métallurgie*, September 1911, vol. viii. p. 655.

alter their manner of distribution. Consequently, if the banded structure were due simply to initial crystallisation of ferrite on these inclusions there should be little, if any, alteration in the parallel arrangement of the pearlite in the slowly cooled piece. Such, however, is not the case; even with a very slow rate of cooling no banded structure is produced, a fact that was noted by Stead[1] some years ago. For example, Fig. 7 (Plate XXVII.) shows the structure of a steel plate containing an excessive amount of non-metallic inclusions, chiefly silicates. The appearance of the same steel after it had been heated at about 1200° C. for two hours, air-cooled, heated again to 950° C. and then slowly cooled, is seen in Fig. 8. Here, no ferrite lines had formed, notwithstanding the presence of many inclusions.

For the formation of ghost lines and the banded structure, heterogeneity of some kind in the metal itself seems essential, but evidently that of phosphorus cannot be the only factor concerned. Between Ar3 and Ar1, one area appears capable of transferring carbon in solid solution to another which differs from it either in composition or physical properties, and the result of this displacement is plainly seen in a concentration of pearlite at the junction of the two.

Summary.

1. It is shown that only when variations in the percentage of phosphorus between two adjacent areas in iron exceed 0·07 per cent. do they cause the removal of carbon, between Ar3 and Ar1, from the richer area.

2. Evidence is given showing that in certain cases carbon may actually move from one region to another of higher phosphorus concentration.

3. The theory that ghost lines are due to crystallisation of ferrite on non-metallic inclusions is considered, and facts are given which show that they cannot adequately be accounted for in this way.

[1] *Journal of the Iron and Steel Institute*, 1918, No. I. p. 287.

Iron and Steel Institute.

THE INFLUENCE OF SEGREGATION ON THE CORROSION OF BOILER TUBES AND SUPERHEATERS.[1]

By G. R. WOODVINE and A. L. ROBERTS (Shrewsbury).

Rapid steaming, due to the use of high-pressure water-tube boilers and superheaters, which has undoubtedly led to fuel economy, has also raised important questions relating to boiler-making materials. Whilst many valuable observations have been made on the treatment of feed-water, not much appears to have been done to improve the mild steel vessels in which the treated feed-water is converted into steam. The general specification of tubes, for instance, stipulates an average chemical composition and certain mechanical properties, but it says nothing about the uniform distribution of the chemical elements, which is likely to be fundamentally important if the electrolytic theory of corrosion is reasonably correct. With the fire-tube type of boiler, working at low pressures, the condition of the mild steel tubes may be less important than in the case of water-tube boilers in which the tubes are usually smaller and have thinner walls. In the latter case the condition of the interior of the tube is of great importance.

It appears to be generally believed that steel tubes should be made from ingot material of the non-piping variety, *i.e.* instead of a shrinkage cavity the ingot contains blowholes whose total volume is about equal to the shrinkage of the fluid steel. The outer portion of such ingots appears to consist of chill crystals formed by comparatively rapid cooling against the faces of the ingot mould. Within this envelope of chill crystals the fluid steel liberates its occluded gases and is thereby kept in movement and at an equalised temperature, until it freezes and fixes in position some of the liberated gas bubbles. A macro-etched transverse section of such ingot material is reproduced in Fig. 1 (Plate XXVIII.). This type of unsound ingot material has been

[1] Received February 15, 1926.

described by Stead, Heyn, Brearley, and others, and appears to be the source of tube troubles with which the present authors have been intimately connected.

Whether the tube billets are pierced by a press or by a rotary piercer, the blowholes and segregates indicated in Fig. 1 will, if present, be found in the interior of solid drawn tubes. By the rotary piercer method, which is more severe on the billet, the pierced steel may be split internally in a position corresponding with the string of blowholes on the interior edge of the chill crystals. It happens occasionally that the annular splitting occurs before the tube is completely pierced ; an example of this is illustrated by the sulphur printed section seen in Fig. 2. When pierced by a press it seems unlikely that the segregated interior of the tube will also be unsound, because it has been torn apart during the piercing operation.

For some time the authors have been making sulphur prints of tubes chosen at random from consignments of new tubes supplied for water-tube boilers and superheaters. In most instances the sulphur prints (Fig. 4, Plate XXIX.) show that the interiors of the tubes consist of badly segregated material. From a sulphur print taken on photographic paper it is not always possible to distinguish spot segregates corresponding to blowholes in the ingot material, but a sulphur print, taken direct on to a lantern slide, can be projected on to a screen and examined at any desired magnification. Actual unsoundness can sometimes be detected in the segregated interior of a new tube, an example of which is reproduced in Fig. 3.

The composition of material machined from the inner and outer zones of tubes such as are shown in Fig. 4 is given below :

	Inner Zone. Per Cent.	Outer Zone. Per Cent.
Carbon	0·11	0·06
Silicon	traces	traces
Manganese	0·43	0·40
Sulphur	0·085	0·030
Phosphorus	0·030	0·020

In order to determine the extent to which pitting and general corrosion in tubes could be ascribed to segregated ingot material, the following experiments were made under closely watched service conditions. Two 12-foot lengths of 1½-inch solid-drawn

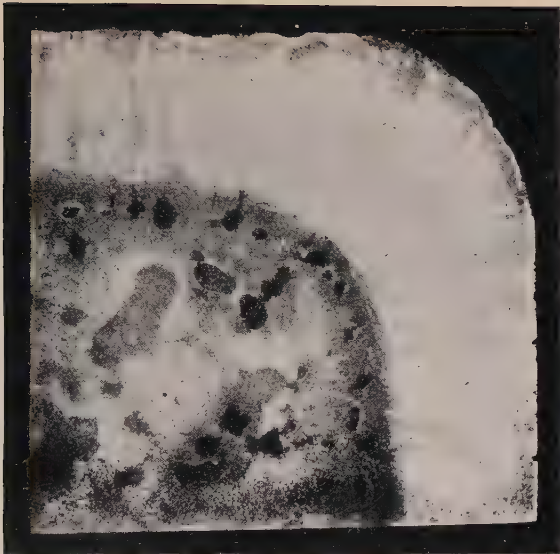

FIG. 1.—Macro-etched transverse section of ingot material.

FIG. 2.—Showing annular splitting in partially pierced billet.

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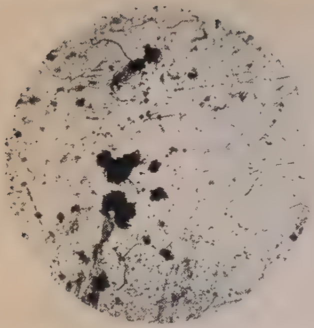

FIG. 3.—Segregated interior of new tube. ×100. (Reduced to $\frac{3}{5}$.)

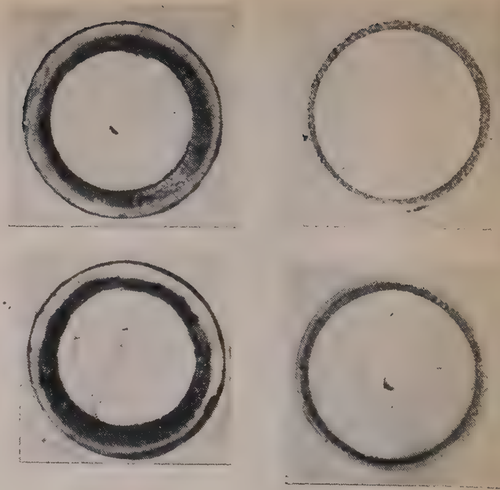

FIG. 4.—Sulphur prints of tubes showing badly segregated material. × $\frac{1}{2}$.

FIG. 5.—Tubes after 12 months' service. Left—Unsegregated. Right—Segregated.

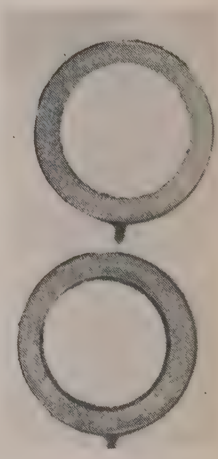

FIG. 6.—Sulphur prints of tubes made from sound steel.

tube were selected, one segregated on the inside and the other free from segregates. These were arc-welded into one length and coiled to form a superheater. The coiled tube was placed in a boiler of 200 lbs. working pressure and used as a superheater under normal conditions. The average steam temperature would be between 600° and 700° F. (316° and 371° C.).

After about twelve months' use perforations appeared in the segregated length, so the coil was removed and different lengths of the two joined tubes were split open. The unsegregated tube was sound and not much the worse for wear (Fig. 5, left, Plate XXIX.), whereas the segregated tube was badly corroded and perforated (Fig. 5, right). The scale removed from the corroded interior of the segregated tube contained 0·19 per cent. sulphur.

A second coil made from a single tube known to be free from interior segregation was in use at the same time under the same conditions. This, when dismantled after a similar period of service, was quite sound except for a few isolated and comparatively slight pittings.

The authors' practical experience of coils of this type is that they always fail in some segregated portion, and where it has been possible to get positive evidence from service failures the trouble could usually be traced to segregated steel. The corrosion is not limited to the wet steam portion of the coil, nor to the part nearer the fire.

Failures of a similar kind occur in water-tube boilers, the small pits first formed gradually joining up to form hollows and deep grooves. This trouble may be attributable in part to the use of bad feed-water, but it is largely due undoubtedly to electrolytic action promoted by blowhole segregates.

Having concluded that tube failures were frequently due to the use of segregated ingot material, attempts were made to buy tubes free from segregates; this was found to be exceedingly difficult. Tubes made from special Swedish billets were not reliable. The difficulty was overcome eventually by purchasing a cast of steel made with all the care devoted to the making of high-grade alloy steel ingots. The ingot material was sulphur printed, and a number of billets made from stipulated parts of the ingot were similarly tested. Tubes made from this cast of

steel were found to be free from segregates, as may be judged from the sulphur prints taken at random, and reproduced in Fig. 6 (Plate XXIX.). The material was also notably free from slag. The composition of this steel is similar to that given in the usual specification for boiler tubes, except that the silicon is higher. This might be expected in acid steel, and it may have been helpful in making a sound steel.

The results of using tubes made only from sound steel have been most gratifying. Laboratory tests have been carried out over a long period and no failures whatever have been recorded. The authors' belief in the connection between segregated ingot material and defects in such tubes has been established by the observations and tests described. It may be that other tube failures, ranging from domestic hot-water systems upwards, are to some extent related to the same causes.

CORRESPONDENCE.

Mr. E. Adamson (Sheffield) wrote that the authors had done a great service, not only to steel manufacturers, but also to users of solid drawn tubes, by showing that non-piping ingots produced a more corrosive material than well-made steel. The results disclosed, however, were not surprising when the details of manufacture of the non-piping variety of steel were followed. In such steels the chief object was to produce blowholes in the ingot in the position shown by the authors in Fig. 1, but unfortunately that steel was so lively in the ingot mould that it was not always possible to do so. As had been shown by Hibbard, the blowholes were sometimes wilful, and would not always make their appearance just in the position desired in the ingot.

It was very satisfactory, therefore, that the class of steel which experienced British steel-makers would consider a normal quality would stand the stringent test of corrosion. Non-piping steel was not looked upon abroad as "quality" material, which view was justified by the authors' results.

Presumably in using the word "segregation" the authors referred to the blowholes in the ingot. Would it not, therefore, be more strictly correct that the title of the paper should be "Influence of Non-Piping Steel on the Corrosion of Boiler Tubes and Superheaters"?

Mr. H. Brearley (Member of Council) wrote that his limited experience of the corrosion of weldless boiler tubes confirmed the main conclusion reached by the authors. On two or three occasions he had found that the oxides scraped from corrosion pits were very high in sulphur, and he had also found that tubes which had proved unsatisfactory in service were associated with the kind of sulphur print reproduced in the paper, but he did not remember the two observations being linked together so suggestively as had been done by the authors. It would be an exaggeration to claim that localised corrosion in boiler tubes was invariably due to the use of segregated material, but it seemed to him to be desirable that large users of tubes should make critical observations on the lines suggested in the paper, in order to confirm the authors' conclusions or to modify them.

Mr. Henry D. Hibbard (New Jersey, U.S.A.) wrote that the paper was a valuable contribution, but it should be borne in mind that it related solely to seamless tubes. The difference in manufacture between the latter and welded tubes was so radical, and the kind of steel most suitable for one so different from that which was best for the other, that each should be considered by itself. For welding, rimmed steel was best; for piercing and drawing, killed steel was most suitable.

A well-made rimmed steel ingot had a sound, clean skin, 2 or 3 inches thick, and then a deep-seated zone of intermediate gas-holes, inside of which the central metal was notably segregated, and usually held a few gas-holes. In making welded tubes the skelp was raised to a welding heat, and the gas-holes, already closed by two rollings, were usually welded up as a consequence as well as the seam. Then the surface of the metal exposed to the fluid within the tube when in use consisted of the exterior skin-metal of the ingot, which resisted corrosion better than the interior metal. The latter point would, of course, be true of a seamless tube made by working a circular plate into a tube by cupping and drawing.

In a seamless tube made by piercing and drawing, the internal skin consisted of the interior metal of the ingot. Whether the steel were killed or rimming that metal was more impure, at least when obtained from the upper part of the ingot, than the outer skin metal. In that respect killed steel was better than rimmed steel, because (1) it was less segregated, and (2) it was free from gas-holes. For those reasons it should be foreseen that the interior skin metal of a tube made of rimmed steel would, or might, be the most impure, and likely to be ragged and rough, if not indeed torn. In making such a tube the steel was not raised to a welding heat.

In view of those considerations, the authors' findings were to be expected. Steel for seamless tubes, made by piercing the billet and drawing, should not evolve gas in the mould. With correct melting-furnace treatment and suitable additions of gas solvents, it should lie dead in the mould, and solidify without escape of gas and with minimum segregation.

Engineer-Captain J. A. Richards wrote that some of the most important specifications for steel boiler tubes did not stipulate the average chemical composition, and, he thought, wisely so. If the specification mentioned the uniform distribution of the chemical elements there would be some difficulty in ensuring that that were complied with. His experience of specifications generally was that it was better not to specify anything unless there were some element of certainty that it would be carried out in practice.

Regarding the remarks concerning "non-piping" steel, he was of opinion that if the steel were carefully made it would give good results for boiler tubes, but experience had shown that difficulties had arisen when using "piping" steel. When the "non-piping" steel was properly manufactured, the blowholes were situated between one-quarter and one-third of the radius of the ingot, and it had been proved in practice over many years that those blowholes welded up perfectly in the billet and remained in a similar position in the wall of the tube, and not on the internal surface, as stated by the authors.

All the boiler tubes for the Admiralty were made from ingots of the "non-piping" variety. He had some samples of tubes taken

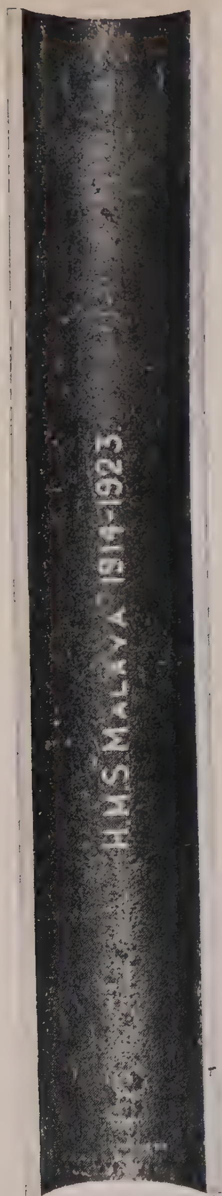

FIG. A. Photograph of the interior of a boiler tube removed from H.M.S. "Malaya."

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FIG. B.—Sulphur print of a longitudinal section of the tube.

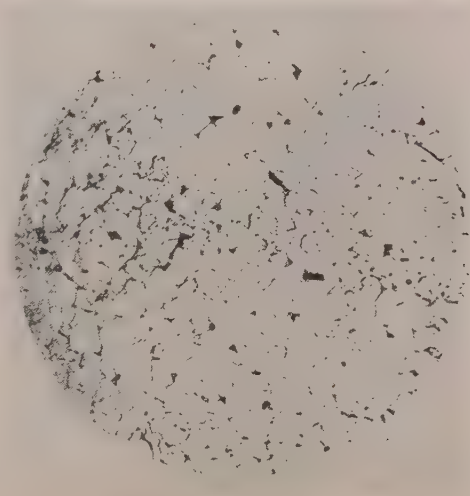


FIG. C.—Micrograph of the outside of the tube.

FIG. D.—Micrograph of the inside of the tube.

from H.M.S. *Malaya* at Portsmouth in 1923. He was much interested in them, as they were manufactured in 1913, and were the first boiler tubes for a battleship made from British steel, Swedish steel having been previously used. When he knew that the periodical test of the boilers was taking place, he went to Portsmouth and selected two average specimens from those which were the most corroded. A photograph of one of the interiors is reproduced in Fig. A, Plate XXIX A. The maximum depth of pitting, after nearly ten years' service, was 0·015 inch. He had just heard from the ship that there had been little or no further wear of the tubes since 1923. They were in excellent condition and appeared good for many years' service. They were manufactured from billets pierced by a rotary piercer.

Regarding Fig. 2 of the paper, he had been intimately connected with all the important tube works in this country for many years, but never saw such a phenomenon. It must happen very occasionally, and not in the best practice. In the chemical composition reported in the paper, the sulphur on the inner zone appeared to be abnormally high, and would seem to be a very extreme case. He could echo the authors' remarks that it was extremely difficult to buy steel free from segregates, though it was easy enough to obtain very special steel for a laboratory experiment, or even for a comparatively small quantity of tubes. He had been under the impression that segregation occurred in all steel, but apparently the authors had reached a happy consummation and had been able to buy steel free from that defect.

One of the most important factors which influenced the longevity of boiler tubes was the facility for cleaning the tubes internally. In the Navy, in normal times, the tubes of water-tube boilers frequently lasted the life of the ship, and they were all made from "non-piping" steel. During the war there was much less opportunity for cleaning the tubes, so their longevity was very much less. Bearing on that, of course, was the design of the boiler and the accessibility of the tubes for cleaning. Generally speaking, it was easier to clean tubes of larger diameters than those of small size. The quality of the feed water had also to be taken into account.

Mr. L. W. Schuster (Manchester) wrote that he had run across cases of a very mild form of segregation at the inside of tubes which did not appear to have arisen in exactly the manner described by the authors, and it would be of interest to know their views as to the manner in which it had formed. The tubes in question failed in service, and the following were the details:

Example 1.—A tube, one of several from a water-tube boiler, which, after two years' service, developed circumferential fractures originating at the inside. The material was free from non-metallic matter and blowholes. Several sulphur prints were taken, on both transverse and longitudinal sections, and all indicated the same feature. The sulphur print (Fig. B, Plate XXIX B.) showed clearly the difference in

appearance of the outside from that of the inside. The inside lay to the right of the print, and some of the fractures referred to were to be seen in that area.

Under the microscope, the higher sulphur was seen to be associated with a markedly higher carbon content, a feature evident from the two micrographs, Figs. C and D, showing, respectively, the outside and the inside of the tube. An analysis failed to show any material difference between the two carbon contents, while there was no great difference between the sulphur values. The figures were as follows :

	Inside of Tube.	Outside of Tube.
	Per Cent.	Per Cent.
Carbon	0·15	0·13
Silicon	0·01	0·01
Manganese . . .	0·39	0·35
Sulphur	0·034	0·014
Phosphorus . . .	0·014	0·008

The material, under the microscope, was quite free from non-metallic matter and signs of oxidation. The failure of that tube did not appear to be connected in any way with the difference in homogeneity of the material, but to be entirely the result of pitting by magnesium salts present in the feed, and of strains due to the too rigid fixing of the drum to which the tubes were connected.

Example 2.—This comprised two tubes, picked out of a batch of several which failed in a water-tube boiler; the bottom portions bulged after the tubes had been in use for a period not exceeding eight years. Sulphur prints [1] showed the same features as were apparent in Example 1; for one print, the section was cut through the centre of the bulged portion, at which point the outside surface was burnt away, while for the second print, a portion of the ring was cut away for further tests before the print was made. The metal was free from non-metallic matter and blowholes.

Analyses of the top part of one of the tubes—*i.e.* away from the bulge—showed, again, no appreciable difference between the two portions, the results being as follows :

	Inside of Tube.	Outside of Tube.
	Per Cent.	Per Cent.
Carbon	0·14	0·14
Sulphur	0·01	0·005
Phosphorus . . .	0·01	0·01

[1] Sulphur prints and a photograph relating to this example will be found in Figs. 67, 68, and 70 of the *Technical Report of the British Engine Boiler and Electrical Insurance Company, Ltd., for* 1925, by courtesy of whom Figs. B, C, and D are reproduced.

The bottom of the tube was completely decarburised, and showed grain-growth at the surface exposed to the boiler fire, and both surfaces were oxidised. The trouble resulted from the metal being overheated owing to it being subjected to an intense local heat from the fire, failure being aided by the presence of scale from the water on the inside of the tubes. A replacement tube in the same boiler, which split after nineteen days' service, did not show the mild form of segregation referred to.

While those examples showed points of distinct similarity to the cases cited by the authors, they did not reveal the same harmful segregation. The sulphur prints showed a conspicuous difference in the composition of the outside and the inside of the tubes, but chemical analysis made no such discrimination. Also, the metal was in each case free from non-metallic impurities and blowholes.

As it did not appear feasible that any local segregation in the ingot should always make its appearance at the inside of the tube, that mild form of segregation hardly seemed to be caused in quite the same manner as the cases mentioned by the authors.

Although the writer had not met with the more virulent form of segregation in tubes mentioned in the paper, he did from time to time meet with an exactly similar form in structural parts, where it had been the cause of not infrequent failure, and had led to an interesting type of fracture.

The authors replied that they were unable to say whether blown ingots dissociated, if it were possible, from blowhole segregates would produce good or bad tubes. Blown ingots appeared to be invariably associated with blowhole segregates, which in the authors' opinion were responsible for the kind of corrosion described in the paper. On that account it was thought better to emphasise segregation, rather than the blowholes from which it arose, in the title of the paper. Segregates might, of course, occur in piped ingot material free from blowholes, and they did not doubt that such segregation, suitably located in a tube, could produce marked corrosion.

Mr. Hibbard's remarks about welded tubes were undoubtedly correct, although it was not clear why, even for such tubes, there should be a technical advantage in using blown ingot material. He appeared to think it important that blown ingot material should be worked at a welding heat. His idea might be justified by some desired mechanical properties in the tube, but so far as corrosion was concerned, it was the segregate in the blowhole that mattered. The blowhole itself, or the supposed degree of perfection with which it had been welded up, appeared to be of minor importance.

Mr. Schuster was concerned about sulphur prints which "showed a conspicuous difference in the composition of the outside and the inside of tubes, but chemical analysis made no such discrimination." The figures he gave showed that the inside of the tube contained at least

twice as much sulphur as the outside of the tube; a ratio of two to one disclosed by chemical analysis was discrimination enough to account for a good deal of blowhole segregation. Whether the segregation on the inside of a tube were " blowhole " segregation or " pipe " segregation could usually be determined by making a sulphur print on a lantern slide, and observing its magnified image. It was quite possible, of course, that the two failures mentioned by Mr. Schuster had nothing to do with the use of segregated steel. Tube failures might be due to mechanical causes, and tubes might even fail by corrosion under circumstances where the use of the purest and soundest mild steel imaginable would have been no great improvement. The object of the paper was to relate a personal experience with corroding boiler tubes, and to suggest that in many cases corrosion might be due to segregation, in particular blowhole segregation, which appeared to account for the troubles described.

Captain Richards' experience with boiler tubes made from blown ingot material was undoubtedly larger and apparently much happier than the authors'. The sulphur prints reproduced in the paper were typical of about 80 per cent. of the tubes examined over a long period. A segregated tube was now very rarely found, and in the authors' experience that complete transformation had been made both possible and practicable by specifying the kind of ingot material required. It would, no doubt, be more difficult, and perhaps impracticable, to frame a specification which could be efficiently applied to blown ingot material intended for tube making. Captain Richards, like other contributors, appeared to think that the crux of the blown ingot question depended upon whether or not the blowholes welded up, but to the authors the goodness of the weld was relatively unimportant, so far as corrosion was concerned. The fact that blowholes in ingot material never welded completely [1] might be important in other respects. The statement, backed by Captain Richards' authority, that all Admiralty tubes were made from blown ingot material, was very interesting; it might be taken to prove that both good and bad tubes were made from blown ingot material. The " good " tubes might be regarded as " good " in two respects, first because segregated tubes were good enough for some purposes, and, secondly, because some of the tubes made from the same ingot material were not segregated.

The authors thanked those who had contributed to the discussion, and hoped that readers of the paper who were makers and users of tubes would take an experimental interest in the subject, so that more might be known generally about those tube failures which were now accepted as a matter of course, and might really be easily prevented by simple means.

[1] *Journal of the Iron and Steel Institute*, 1921, No. I. p. 27.

1926, No. I.; Vol. CXIII. Annual Meeting, June 3–4.

Iron and Steel Institute.

COAL BLENDING.[1]

A REVIEW OF GENERAL PRINCIPLES AS APPLIED BOTH TO HIGH- AND LOW-TEMPERATURE CARBONISATION.

By DAVID BROWNLIE, B.Sc. (Hons.) Lond., F.C.S., M.I.Chem.E., A.M.I.Min.E., Etc.

Introduction.

In this paper the author attempts to present a survey of the subject of coal blending in connection with carbonisation, that is, primarily, the mixing of swelling bituminous coals with other products, such as non-swelling bituminous coals, anthracites, and anthracitic coals, high-temperature carbonisation coke, which may be either metallurgical or household gas coke, low-temperature carbonisation fuels, oxidised coals, and various constituents of coal. It is necessary likewise to make reference to the use, for the same purpose, of various carbonaceous materials, such as brown coal, lignite, shale, cannel, and general canneloid material, as well as pitch, oils, and tars, and also to the possible application of petroleum and similar natural products.

Unfortunately the rapidly growing complexity of the subject of carbonisation in general renders it difficult to find adequate definitions, but the author employs the popular term "low-temperature carbonisation" in its broadest sense, to cover all methods for the treatment of raw coal and other carbonaceous material which involve a greater or lesser degree of carbonisation or heating, as distinct from the familiar high-temperature carbonisation processes of the coke-oven and the gasworks. The term "low-temperature carbonisation" was originally applied to the simple process of carbonising bituminous or semi-bituminous coal in a retort at about 1000° F. (538° C.) instead of 2000° F. (1093° C.), so as to obtain a higher yield of more valuable tar with less pitch, and a smokeless, free-burning fuel, or semi-coke, containing a considerable residue of the original volatile

[1] Received February 1, 1926.

matter. Also the yield of ammonia and gas was consequently lower, but the latter was of a very rich quality. To-day, however, what is generally understood by "low-temperature carbonisation" has gone far beyond this simple principle, but in the present paper a better definition than the rough-and-ready one already mentioned will not be attempted.

As the result of a prolonged study of low-temperature carbonisation, the author is in possession of details, more or less complete, of over 120 different processes as applied to coal and other fuels, and there are hundreds of British patents alone on the subject. These facts are mentioned for the reason that many people can hardly be brought to realise the importance, as well as the intricate nature, of the problems of the scientific utilisation of raw coal and fuels generally. In fact, had the scattered information been available in a comprehensive and condensed form, half the present processes might have been spared, as well as many ludicrous expressions of opinion.

The matter is of interest to the iron and steel industries for two main reasons. First, the improvement of net efficiency in the production of metallurgical coke. Secondly, it will be impossible to carry on the industry much longer in Great Britain with the present wasteful use of coal, and the adoption of more efficient methods is becoming a national necessity.

Dealing with the first point, it is familiar knowledge that only a certain proportion of coal is suitable for coking—that is, possesses sufficient resinous or cementing constituent of suitable quality to bind the whole mass of the charge into a homogeneous and coherent coke without undue swelling and reduction in density. Non-coking coals, however, may be of two classes, the more common of which has a deficiency of cementing material, giving a carbonised residue that is powdery. The second class of non-coking coal may, on the other hand, contain such an excess of resinous material that it causes the charge to swell unduly, giving porous and soft coke.

Professor S. W. Parr,[1] with his associates at the University

[1] S. W. Parr and C. K. Francis, "The Modification of Illinois Coal by Low-Temperature Distillation," *University of Illinois Bulletin, No.* 24, 1908.

S. W. Parr and H. L. Olin, "The Coking of Coal at Low Temperatures," *University of Illinois Bulletin, No.* 60, 1912.

S. W. Parr and H. L. Olin, "The Coking of Coal at Low Temperatures, with Special Reference to the Properties and Composition of the Products," *University of Illinois Bulletin, No.* 79, 1915.

of Illinois, was the first to prove conclusively, by his investigations commenced in 1902, that, in order to obtain a coherent coke, the original coal must not only contain just the right amount of resinous material, but that this constituent must also have a definite melting point, generally about 662° to 842° F. (350° to 450° C.), and the property of not decomposing until at a temperature considerably above the melting point, so that the viscous stage can be retained for some time, thus enabling thorough penetration and mixing to take place. Incidentally, it may be pointed out that the mechanical structure of the raw coal plays a more important part in the production of good coke than is generally supposed, as shown by F. C. Keighley.[1]

The general method of blending as developed on scientific lines by Parr is of the greatest importance, as it increases very considerably the amount of coal available for the production of a high-grade coke. It is already common practice to-day to crush, grade, wash, and dry the coals, and to compress the charge in the oven before carbonisation, and by the adoption of the further process of blending great improvements result. The mechanical operation of the ovens is improved, for the use of coals with slightly too much resinous material causes a severe strain on the walls and general setting because of undue swelling, while the considerable friction and resistance on discharging increase the wear and tear and cost of repairs and maintenance.

It cannot be too strongly emphasised that in the matter of blending the British coke-oven industry is lagging behind both the United States and the Continent. In America coal blending for coking is almost universal, the plants as a rule being situated at the steelworks, while the coal is brought from many different districts and generally stored in different bunkers and bins, whence it is taken to the mixing chambers by means of continuous belt conveyors; or, the correct number of car-loads are used for a large mix, with the balance weighed separately if necessary, so as always to keep to the exact blend which experience shows to give the best results, two of the essential factors in successful blending being accuracy and intimate mixing.

The same applies more or less to Germany, Belgium, and France, a good example being the methods now adopted in the

[1] F. C. Keighley, "Coking and Non-Coking Coals," *Iron Age*, 1907, vol. lxxx, p. 364.

Saar district. Of course, there are also a number of British plants in which modern blending is being carried out, but the fact remains that in Great Britain adequate attention has not been given to the subject.

Another point of great importance to the iron and steel industries is the fact that British coking plants are as a rule so small and scattered that the resulting bulk supplies of coke are not uniform in quality. It would be, for example, a much more efficient national policy to divide the colliery districts into areas according to circumstances, have a few very large modern coking plants, blend all the coal received from the many different collieries and produce a more uniform quality of coke, which probably also would allow the use of about 25 per cent. of small non-coking coal, at present practically a waste product. As regards low-temperature carbonisation Great Britain is peculiarly well situated for scientific methods of fuel utilisation, possessing a large proportion of rich bituminous coal which would give a high yield of by-products, with the added advantage of relatively short railway journeys in comparison with other countries, especially the United States.

Again, the subject is of direct interest to the iron and steel industries on account of the improvements rendered possible in gas-producer practice, as found by German experience. The low volatile fuels obtained are in general very suitable for this purpose, giving less trouble than bituminous coals, while there is much to be said for combined low-temperature carbonisation and gasification in the same setting.

The latest developments in the treatment of raw coal, according to a number of different processes, seem to be tending to the production of a smokeless fuel that possesses extremely reactive chemical properties, and is therefore of particular value for gas-producers. In fact, the stage may shortly be reached when it will be the best policy in many cases to subject a great part of the coal to low-temperature carbonisation for the specific purpose of power generation by means of gas-engines, and to obtain enriched producer-gas from the residual fuels, with cracking or hydrogenation of the greater part of the tar oils to light fractions, in preference to using internal combustion heavy-oil engines.

The adoption of suitable carbonisation processes with the aid of blending would also be of great value in enabling coke-oven

installations to be usefully employed for turning out smokeless free-burning fuel for various markets in slack periods, since, with the present general methods, a large amount of valuable plant is always liable to be standing idle as the trade fluctuates.

Further, low-temperature carbonisation is becoming increasingly important for the production on the spot of a fuel for blending with any strongly swelling coal. For instance, in the Saar, a proportion of the available coals is submitted to low-temperature carbonisation, and the residual smokeless fuel, after the separation of the by-products, is blended in with the main bulk to give a dense coke, thus eliminating the cost of carriage and dependence on other areas for blending material.

Since the subject of blending in general is of formidable magnitude, for convenience and in special reference to the iron and steel industries the present paper will be divided into the following sections:

1. A preliminary reference to the blending of carbonaceous materials for purposes other than that of carbonisation, such as combustion and gasification.
2. Rare cases of certain coals, especially in relation to low-temperature carbonisation, which do not require blending as they contain exactly the right amount of resinous material to give a homogeneous coherent coke without swelling.
3. Blending of two or more coals, that is, the general principle of mixing strongly swelling bituminous coals having an excess of resinous material with non-swelling coals deficient in this respect.
4. The use of high-temperature carbonisation coke instead of non-swelling coals for blending with strongly swelling coals.
5. The blending of swelling coals with low-temperature carbonisation fuels.
6. Application to blending of the use of oxidised or preheated swelling coals in which the coking properties are entirely destroyed and the product then used for mixing.
7. The utilisation of anthracite, anthracitic, and non-caking coals in coke production by blending with high- or

low-temperature tars, pitch, or oils, as well as petroleum or other similar natural products.

8. Blending in the brown coal and lignite carbonisation industries.
9. Shale blending.
10. Chemical methods in blending.
11. A brief reference to a number of typical low-temperature carbonisation processes of special interest to the iron and steel industries, and in which blending in general plays an important part. The following is a list of these:

    (1) Carbocite Dual Carbonisation (Canton, Ohio, U.S.A.).
    (2) Coalite (London).
    (3) Delkeskamp (Berlin).
    (4) Dobbelstein (Essen).
    (5) Fellner and Ziegler (Westphalia).
    (6) Fusion Retort (Middlewich).
    (7) Kohlenscheidungs Gesellschaft (Essen).
    (8) Maclaurin (Glasgow).
    (9) Midland Coal Products (Nottingham).
    (10) Nielsen or "L.N." (London).
    (11) Pure Coal Briquette (Leigh, Lancashire).
    (12) Raffloer (Duisburg).
    (13) Smith Carbocoal (New York).
    (14) Staveley Coal and Iron (Chesterfield).
    (15) Summers Continuous Coking (New York).
    (16) Tozer (London).
    (17) Thyssen (Mülheim).

1. A Preliminary Reference to the Blending of Carbonaceous Materials for Purposes other than that of Carbonisation, such as Combustion and Gasification.

In the first place, it may be pointed out that the principle of blending as applied to coal and other fuels for ordinary combustion has probably been deliberately practised for thousands of years. The Romans used mixtures of coal and wood to heat their public baths, as known, for example, from the excavations

at Uriconium, near Shrewsbury. Also it has been common practice ever since the practical development of the steam boiler by Savery in 1698 to use as much as possible of the cheap small coal to mix with the ordinary saleable varieties. The early pioneers of the mechanical stoker, particularly William Brunton, whose first stoker dates from 1819, and John Juckes with his chain-grate stoker of 1841, laid great stress on the value of their appliances in being able to use blended or mixed coals in this way. It is well known to be common practice for steam users to burn two coals together, especially if one is of a lower and cheaper quality than the other, but in most boiler plants not nearly enough attention is given to this question of blending fuels, chiefly because, in average installations, even of large size, no scientific methods of control are adopted, especially in the way of boiler feed meters, steam meters, automatic gas analysing machines, and pyrometers. Consequently the exact performance always remains unknown and renders it impossible to find out the true saving obtained by blending. In many cases, black smoke from steam boiler and other furnaces can often be minimised or prevented altogether by blending, some varieties of bituminous coals of the best quality being excessively smoky for no very obvious reason, just as others give less trouble than usual. Blending also enables the utilisation of low grade and refuse coals at collieries, as well as coke breeze from coke-ovens and gasworks. Millions of tons of coke breeze have been thrown away as refuse, a practice still in vogue even to-day, in spite of the fact that such material is excellent fuel for steam generation when blended with coal or coke, just as is the case with fine anthracite "duff" or "culm." Considerable attention has of late been given to this latter subject in the United States.[1]

The obvious advantages attainable by the use of low-grade fuels, blended or otherwise, are apparent as the result of the invention of improved forced-draught furnaces and other appliances for ordinary cylindrical boilers, and of special types of travelling grate stokers for water-tube boilers, while ordinary chain-grate stokers can now be used for burning blended mixtures of coal and small coke on the "sandwich" system of E. W. L. Nicol.

[1] "Burning Steam Sizes of Anthracite with or without Admixture of Soft Coal," *U.S. Bureau of Mines, Technical Paper No.* 220, 1919.

A further example of the value of coal blending for combustion is in connection with pulverised fuel firing, now making enormous strides. A product of less than about 3 per cent. volatile matter, such as coke or anthracite, may be used by this method, but it is generally better policy to blend with a little bituminous coal or similar fuel to raise the volatile matter to 5 per cent. or over.

Again, in producer-gas practice attention has been given to the blending of bituminous coals with coke breeze, so as to prevent the difficulties in the generator due to the charge tending to cohere and obstruct the even passage of the air and steam blast. In this connection W. A. Dunkley[1] describes experimental work carried out with a plant of five producer-gas generators at the works of the Coal Products Manufacturing Company of Illinois. Promising results have been obtained with bituminous coal blended with 20 to 25 per cent. of coke breeze, and of course low-temperature fuels could be used in the same way.

2. Rare Cases of Certain Coals, especially in Relation to Low-Temperature Carbonisation, which do not require Blending as they Contain exactly the Right Amount of Resinous Material to give a Homogeneous Coherent Coke without Swelling.

A good quality coking coal for high-temperature carbonisation in coke-ovens naturally does not need to be blended, since it already contains the correct amount of bituminous or cementing material to form a hard, close-grained coke without undue expansion. But it is extremely interesting to note that a certain limited proportion of coal is available which is so exactly constituted with regard to the amount and quality of its volatile content that it will answer to the much more severe test of low-temperature carbonisation at, say, 1000° to 1200° F. (540° to 650° C.) without any compression or other preliminary treatment of the charge, and give a dense and non-porous free-burning smokeless product with, say, 10 per cent. volatile matter. Also

[1] W. A. Dunkley, "Bituminous Coal as Generator Fuel for Large Water-Gas Sets with Waste-Heat Boilers," *U.S. Bureau of Mines, Technical Paper No.* 335, 1925.

there is a somewhat greater proportion of coking coals that approach this condition much more closely than the average, requiring very little blending, general preliminary treatment, or compression. Incidentally, these factors make it extremely difficult to judge of the value of many low-temperature carbonisation processes without knowing the exact practical properties of the coal that has been used for the determination of test results.

These conditions were probably known to many of the earlier workers, including Thomas Parker, but they were first investigated on scientific principles by Parr,[1] who gives a number of examples of Illinois coals possessing this property. In Fig. 1 (Plate XXX.) is reproduced, from Parr's work, a photograph of a low-temperature carbonisation fuel obtained by simple heating at 842° to 932° F. (450° to 500° C.), from a particular Southern Illinois coal (Williamson County). As seen, it consists of an extremely close and fine-grained smokeless coke, having 11·50 per cent. volatile matter and a density of 0·750, while being very strong both in tensile and compression tests, so that it could be handled without undue formation of dust and small material.

In general, Parr's experiments showed that a few coals will give by direct carbonisation a hard and compact smokeless fuel or "semi-coke," although most samples resulted in either a very friable or porous material or a granular residue with no coking properties at all, all gradations of properties in these respects being represented.

Dr. S. Roy Illingworth [2] of Treforest has also carried out research work on this point in reference to processes for the carbonisation of coal in two stages. Coals of the special character under consideration he terms the "one-stage" variety, and an example given showed, on the ash- and moisture-free basis, 90·96 per cent. of carbon with 16·94 per cent. volatile matter when heated to 1652° F. (900° C.). On carbonisation in the laboratory this coal gave off no volatile matter at 662° F. (350° C.) and only 2½ per cent. at 752° F. (400° C.), which indicates the suitability of the coal for direct low-temperature carbonisation. Thus at 932° F. (500° C.) 10 per cent. of volatile matter was

[1] S. W. Parr and H. L. Olin, *University of Illinois Bulletin, No.* 79, 1915. See *ante*, p. 230.

[2] S. Roy Illingworth, "Carbonisation of Coal in Two Stages," British Patent 187328, 1921.

evolved with the formation of an extremely hard and dense fuel.

Mention of this phenomenon is also made by Sir George Beilby[1] in his reports to the Fuel Research Board. Thus Dalton Main, a Yorkshire coal, does not swell on low-temperature carbonisation, and in fact shrinks slightly, Fig. 2 (Plate XXX.) being an illustration of the resulting fuel.

Finally, it is interesting to note also that in still rarer cases a perfectly free-burning coke is obtained by simple high-temperature carbonisation in gasworks retorts of the horizontal type, in which, of course, the charge is not even under slight pressure, as in a coke-oven. Edgar C. Evans gives an example of this in connection with the Calcutta gasworks, the coke being entirely different from ordinary gasworks coke. The reason seems to be due largely to the fine-grained structure of the raw coal, while for some reason or other no graphitic carbon is deposited.

3. Blending of Two or More Coals, that is, the General Principle of Mixing Strongly Swelling Bituminous Coals having an Excess of Resinous Material with Non-Swelling Coals Deficient in this Respect.

The blending of two coals together so as to give a better coked product has certainly been practised for over seventy-five years, but it is probably of much greater antiquity. The method was used, for example, by James Palmer Budd of the Ystalyfera Iron Works, in 1850, who clearly described the general principles in his patent as follows :

"I take a quantity of non-caking coal and I take another quantity of the most caking coal I can produce, and I intimately mix these quantities of coal together, with the necessary precautions, and having crushed any lumps that may be therein, I subject the mixture to the ordinary process of coking bituminous coal, and the result will be a good serviceable coke, the bituminous matter of the caking coal, when liberated by heat in the coke-

[1] Sir George Beilby, "Report of the Fuel Research Board for the Years 1920–1921. Second Section : Low-Temperature Carbonisation."

Sir George Beilby, "Preliminary Experiments in the Low-Temperature Carbonisation of Coal in Vertical Retorts," *H.M. Fuel Research Board, Technical Paper No.* 7, 1923.

furnace acting during the process on the particles of the non-caking coal with which it is in contact and cementing the whole into a homogeneous coke."

In general, a blend of 50 per cent. of the two coals was first used, this ratio being altered until the best results were obtained, and it was specifically mentioned that anthracite could be employed. A number of other investigators then copied the method. Blending was also used at a very early stage in France, one example being quoted in 1857 as consisting of four parts of anthracite and one part of caking coal. Coming now to later investigators, coal blending for metallurgical coke production is discussed at considerable length by David White,[1] who gave the figures for the analyses of 319 different American coals, together with the relation between the proportions of carbon, hydrogen, and oxygen, and the coking properties. He stated that some coals which by themselves gave an inferior coke and were high in by-product yield, especially ammonia, were often found in the same pit with good coking coals, so that it was an obvious advantage to blend before coking.

The scientific pioneers of blending two or more coals together, especially as regards low-temperature carbonisation, are Parr and Olin.[2] Their investigations were principally concerned with studying the process of the carbonisation of bituminous Illinois coals at 842° to 932° F. (450° to 500° C.), and they employed a perforated steel cylinder containing the charge, provided with a piston at one end, so as to be able to exert pressure if necessary at the viscous stage, the heating being on the external principle, using superheated steam for convenience of experiment. It was noticed that certain of the different coals were, under given similar conditions, much more viscous than others, so that the charge easily protruded through the holes in the cylinder.

The idea was soon developed of trying the effect of adding to such bituminous coals other qualities deficient in resinous content, particularly anthracitic coals and metallurgical coke breeze, so as to absorb the excess and give a homogeneous close-grained and non-spongy product in which the percentage of resinous

[1] D. White, "The Effect of Oxygen in Coal," *U.S. Bureau of Mines, Bulletin No.* 29.

[2] S. W. Parr and H. L. Olin, *University of Illinois Bulletin, No.* 60, 1912. See *ante*, p. 230.

matter was sufficient to give a coherent coke without undue expansion. It was found that by blending together in a fairly fine state of division strongly swelling bituminous coals with anthracite in amounts varying from 1 to 3 parts of anthracite and 1 part of bituminous coal a highly satisfactory fuel could be obtained. In this work also the principle of "temporary binders" was adopted—that is to say, the blended coals were mixed before carbonisation with some substance such as molasses, which held the coal particles together until the charge attained a sufficient temperature to become viscous and adhered naturally, only a slight pressure being employed, and the molasses, of course, being completely decomposed. As typical of these coal blending experiments Fig. 3 (Plate XXXI.) shows a low-temperature fuel obtained by blending one part of an Illinois swelling coal and three parts anthracite, all through a 20-mesh screen, and made into a temporary briquette with 11 per cent. molasses and carbonised as usual at 842° to 932° F. (450° to 500° C.). This carbonised fuel had a specific gravity of 1·02 and a crushing strain of 650 lbs. per square inch, and numerous other examples are given.

In studying methods for improving the efficiency of high-temperature carbonisation processes, A. Douglas[1] blended together different coking and non-coking coals, and in general showed that in many cases up to 30 per cent. non-coking coal could be added to coking coal without interfering with the quality of the coke; but, of course, the best conditions for any two given coals have to be determined in each case. The improvement in quality of metallurgical coke by suitable blending of coals has also been studied by G. Charpy and M. Godchot.[2]

Further, E. R. Sutcliffe and Edgar C. Evans[3] gave some interesting examples of the blending of coals. Thus Fig. 4 shows the resulting low-temperature fuel obtained from a mixture of the strongly swelling No. 2 Rhondda coal with a highly volatile but non-caking coal. This particular sample of low-temperature fuel

[1] A. Douglas, "Improvement of the Coke by the Blending of Coking and Non-Coking Coals," *Gas World*, 1912, vol. lvii. pp. 415 and 529.

[2] G. Charpy and M. Godchot, "Improvement in Hardness of Coke," *Comptes Rendus*, 1918, vol. clxvi.; *Iron and Coal Trades Review*, 1918, vol. xcvii. p. 344.

[3] E. R. Sutcliffe and E. C. Evans, "Recent Developments in the Technology of Fuels," *Proceedings of the South Wales Institute of Engineers*, 1922, vol. xxxviii. pp. 341 and 445.

is fairly good, but contains too much non-caking coal, and is therefore rather soft. Sutcliffe and Evans state, however, that by suitable blending of coals extremely satisfactory results can be obtained.

Illingworth[1] has devoted much attention to the subject in connection with various low-temperature carbonisation processes. On this principle a swelling coal is blended with a non-swelling coal, so that the mixture has a "resinic content" of certainly not less than 5 per cent., and generally 8 per cent. or over, this term meaning the amount soluble in boiling pyridine, phenol, or chloroform, based on the ash- and moisture-free basis. The blend is then carbonised at a temperature not exceeding 932° F. (500° C.), or 122° to 212° F. (50° to 100° C.) above the minimum temperature at which the resinic matter in the blend is destroyed, and the method is claimed to give direct, without pressure, a hard and dense, smokeless, free-burning fuel. Also the carbonisation can be carried out under high-temperature conditions with the object of giving a better grade of coke.

To quote one example, the bituminous swelling coal, on the ash- and moisture-free basis, showed 31 per cent. volatile matter at 1652° F. (900° C.) and 15 per cent. at 752° F. (400° C.). This was blended with an anthracitic coal which, on the usual basis, had 10·7 per cent. volatile matter at 1652° F. (900° C.) and 0·5 per cent. at 752° F. (400° C.). For the production of a hard and dense low-temperature fuel carbonised at 752° F. (400° C.), the best blend was 45 per cent. of the bituminous coal and 55 per cent. of the anthracitic, corresponding to 6·75 per cent. volatile matter at the temperature of carbonisation. This fuel (55 per cent.) could also itself be blended with the bituminous coal (45 per cent.) to give a good low-temperature fuel on carbonisation, interesting from the point of view of using the smalls.

In another case, Illingworth[2] adapted the principle to the blending of wet coals, as delivered from the washery, mainly with a view to eliminating the trouble in coking practice of having to dry the wet coal down to about 3 per cent. of moisture, which is apt to result in oxidation and deterioration of coking properties. Accordingly, therefore, the idea was to heat a part of the wet coal,

[1] S. Roy Illingworth, British Patent 186085, 1921.
[2] S. Roy Illingworth, British Patent 235627, 1924.

or one of the coals in the case of blending, to a fairly high temperature, up to 572° to 752° F. (300° to 400° C.), out of contact with the air, and then to mix the heated product with wet coal so that the moisture in the latter was suddenly driven off. A series of graphs is given in the patent, showing the theoretical proportions of wet coal containing any amount of water to mix with the heated coal at given temperatures, the average efficiency of the heat transmission being about 82 per cent. In the case of blending of different coals, wet or dry; the final product, of course, had to fulfil the condition of preferably not less than 8 per cent. resinic matter.

H.M. Fuel Research Board [1] have also devoted attention to the blending of two coals, especially from the point of view of low-temperature carbonisation, so as to give a non-expanding mixture.

A large part of the Fuel Research Board's work was undertaken with a blend of strongly swelling Mitchell Main Coal and either the non-swelling Dalton Main quality already mentioned or Ellistown Main, a long flame, non-caking Yorkshire bituminous coal. Thus, for example, a blend of 60 per cent. Mitchell Main and 40 per cent. Ellistown Main is found to give, on low-temperature carbonisation, a dense hard fuel that shrinks slightly. Fig. 5 (Plate XXXII.) shows the fuel obtained from this blend, and the entirely non-coked products that result when the two coals are carbonised alone at low temperatures are also shown, the residue, in one case, being merely a non-coherent powder, and in the other a porous product puffed out to a sponge-like structure.

It is understood that the general process of low-temperature carbonisation at present being investigated by H.M. Fuel Research Board is blending, followed by carbonisation in a simple type of externally heated, continuous, vertical cast-iron retort on the same principle as vertical gas retorts.

In the earlier days of the coke-oven industry in America much work on coal blending was carried out by the United States Steel Corporation. Thus, for example, at the Joliet Works, 60 per cent. of high volatile coal and 40 per cent. of low volatile coal was regularly employed, and, finally, after considerable experience, the figures in some cases were cut down to only 20 per cent. high volatile coal, and many works are now using 20 to 40 per cent. of

[1] *Report*, 1920–1921. See *ante*, p. 238.

such coal. As usual, the extensive experience of the United States Steel Corporation on this question is that no definite rules for blending can be laid down, but in each case the coals have to be tried out experimentally on a large scale until the best blend is found, and then the greatest care must be taken to keep exactly to the correct proportions.

In Great Britain Messrs. The Coppée Company (Great Britain), Ltd., of London, and their affiliated company, Messrs. Evence, Coppée et Cie., of Brussels, have had much experience with the principle of blending as applied to coke-oven operation. P. N. Hambly points out another complication, namely, that the temperature of carbonisation makes a considerable difference to the quality of coke obtained, either from a given coal or a blend of fuels, so that the best proportions for mixing can only be found by taking into consideration two additional factors, the design of the oven and the temperature. Thus in a given case an excellent grade of coke was made from a blend of 55 per cent. good coking coal and 45 per cent. almost non-coking coal when used in silica ovens at the highest temperature. If, however, the same blend were used in ordinary firebrick ovens, and consequently at a lower temperature, the coke was of no practical value. Also it is mentioned that if two coals, each of which used separately gives more or less a good coke, are blended, the result may be a very inferior product. Thus of two coals from South Wales one gave a good coke and the other a second-grade quality as carbonised in the same ovens under identical conditions. When, however, these two coals were blended no coherent coke at all was obtained, a highly interesting matter which certainly requires further investigation. Finally, the Coppée Co. in general do not agree with the idea often held that most high volatile coals give a better result when compressed, and they have had experience of several cases where coal of this character made excellent coke without compression, especially under modern high-temperature conditions.

Messrs. Simon-Carvès, Ltd., of Manchester, have carried out from time to time a considerable number of experiments in coal blending, particularly in the use of mixtures of highly bituminous coking Yorkshire coal and very hard non-coking Nottingham steam coal. It was found that if the non-coking material was

in a fine state of division as much as 40 per cent. could be added to the coking coal without deteriorating in any way the quality of the final coke.

Their general opinion, however, would appear to be that to obtain the best results the conditions of operation must often be varied considerably, not only as to the amounts of the coals used, but also as to the exact methods in working any particular coke-oven plant.

The firm of Heinrich Koppers of Essen (Germany) has successfully used as the more inert constituent low volatile coal, coke breeze, and low-temperature carbonisation fuel. Dr. Koppers has kindly stated that in every case the coal and other constituents must be finely pulverised before blending equivalent to 80 per cent. through an 0·118-inch sieve (3 millimetres), and in most cases it is better also to stamp the blended charge in the ovens. Also he points out that in many cases, for the most successful results, the coal needs a very careful preparation by crushing, screening, and separation of the material under 0·275 inch (7 millimetres). The residual coal is then washed, either by wet or dry methods, while the material under 0·275 inch (7 millimetres) is freed from dust, that is, everything below 0·0098–0·0118 inch (0·25–0·30 millimetre). The grains from 0·0118–0·0275 inch (0·3–0·7 millimetre) are then treated in a vibrating separator to remove iron pyrites and shale, and the final clean product is then dried and further crushed to the size mentioned before blending. In this way, by the most careful methods, good quality metallurgical coke is now being made from coals hitherto considered quite unsuitable.

Dr. Koppers states further that in the Ruhr, which has a number of relatively small coking plants, it would be much better policy, just as in Great Britain, to have only a few very large coking plants, and to blend the coal as it arrives from the different collieries. Further, it may be added that Messrs. The Koppers Coke-Oven Co., Ltd., of Sheffield, have now completed an experimental plant on full working scale at the Tinsley Park Colliery, near Sheffield, consisting of eight ovens with a throughput of 120 to 160 tons of coal per twenty-four hours, in which every arrangement is made for blending coals before carbonising. The ovens are of their latest type, that is, on the narrow taper

principle, constructed of silica bricks, for operation at the highest temperatures.

As typical also of British work in this field one very well-known large iron and steel works in Lancashire has kindly informed the author that their general practice is to blend 20 to 30 per cent. non-caking coal and 70 to 80 per cent. of caking coal, the complete range of coking index covered being 5 to 16, and in this way a high-grade quality of metallurgical coke is obtained. Also they have used with good results 55 per cent. poor coking coal with 44 per cent. caking coal. In general, eleven different types of coal are available for blending purposes at the coke-ovens of this particular establishment, having the following analyses:

No.	Volatile Matter. Per Cent.	Ash. Per Cent.	Sulphur. Per Cent.	Coking Index.
1	34·4	7·5	2·70	14
2	30·2	5·5	2·37	16
3	34·6	8·8	1·82	5
4	33·4	5·2	3·00	12
5	33·3	5·5	2·05	10
6	35·4	5·0	1·75	9
7	34·1	4·9	2·32	10
8	38·4	5·0	3·18	8
9	35·6	7·2	2·48	9
10	33·0	7·2	2·67	13
11	30·5	8·2	2·11	14

As showing the complexity of this question of blending, the firm point out that in one particular mine in the locality are three very different seams from the coking point of view. The bottom seam is an excellent coking coal with an index of about 16, giving by itself a high-grade foundry coke, while it is also a good gas coal, the analysis showing 14 to 16 per cent. ash and 1 per cent. sulphur. On washing, the ash is cut down to 4 to 5 per cent., giving a coke with 7 to 8 per cent. ash and 0·6 per cent. sulphur. The middle seam is a good class coal but with only moderate coking properties, having 8 to 10 per cent. of ash and little sulphur, less than 0·5 per cent. This can be blended 50 : 50 with the bottom seam to give a good foundry coke, although not quite so high grade a product as when the bottom seam alone is used.

Finally, the top seam is a non-caking coal which is not much used for coke, especially as the ash is rather high, the sulphur being about 0·5 per cent. However, a blend of 25 per cent. top seam, 25 per cent. middle seam, and 50 per cent. bottom seam gives a good coke.

On the Continent the Société Générale de Fours à Coke Systèmes Lecocq, of Brussels, have made numerous large scale trials on different coke-oven installations on their system. They give as a typical example a blend of 80 per cent. of strongly swelling Saar coal, with 32 to 35 per cent. volatile matter, and 20 per cent. of very lean non-coking coals containing only 14 to 15 per cent. volatile matter, and state that in general blending is a highly beneficial process if carried out on the right lines.

In France, before the war, most of the coking coal came from the Nord and Pas de Calais areas, but, by the Treaty of Versailles, the Saar mines were awarded to France. These produce, as is well known, chiefly non-coking coal of a strongly swelling character, giving a porous residue with a large proportion of breeze, and in order to solve the problem a Society was formed, "Le Coke Métallurgique," which, by arrangement with the Société Houillère de Sarre et Moselle, organised an experimental and research station at the Hôpital coke-oven plant in Lorraine. This is under the control of M. Baille-Barelle, and most excellent work has been carried out during the past few years. Compression of the charge alone, according to the Schwartz system, with weights on the charge as used in Silesia, proved to be of little value, and blending was adopted, in the first place using imported Belgian anthracite as the inert material, and, secondly, anthracite from the Ruhr. Thus, greatly improved results were obtained with 5 per cent. Belgian anthracite or 15 per cent. Ruhr anthracite, compressing the blend and carbonising at the highest temperature, about 1832° F. (1000° C.). The latest principle in this connection, however, is what is known as the "Rational" process, consisting essentially in heating the charge simultaneously to an equal degree at all points, so as to avoid the formation of fissures, and not raising the temperature to the highest point until the charge is heated through. On these lines, with not too high a final temperature, it is now believed to be possible to turn out high-grade coke from the Saar swelling coals without

any blending, although the total period of heating is much greater than usual, up to fifty hours. On the other hand, the ammonia yield is increased considerably. Finally, it should be mentioned that the subject of blending coals in coke-oven practice has been dealt with by G. A. Hebden.[1]

In connection with the high-temperature carbonisation household gas process, many individual gas managers have doubtless also mixed or blended in a rough sort of way two or more qualities of coal that were available, with a view to improving the process, either as regards the yield and quality of the gas or of the residual soft coke.

The subject is at last beginning to be studied on scientific lines by the gas industry in an attempt to minimise the obvious disadvantages of gasworks coke for household consumption. This was well illustrated at the "Smokeless Fuel (Gas Coke)" Conference.[2] Ever since the gas industry was able to increase the temperature of carbonisation over about 1200° to 1300° F. because of the introduction of the fireclay retort instead of the old cast-iron type, the value of the residual soft gas coke to the average consumer has deteriorated. In fact, for many years coke of this description was a drug on the market, and, as already indicated, millions of tons of coke breeze have been thrown away as refuse. The main troubles with gas coke, so far as domestic and similar uses are concerned, are the low rate of ignition and general chemical inactivity, the objectionable smell of sulphur and other products, with an unpleasant "dryness" in the air, and the large bulk occupied as compared with coal.

From a scientific point of view also, and for general industrial purposes such as boiler firing, one of the main objections is the ready absorption of water, so that even 20 per cent. is easily taken up, and 10 to 12 per cent. water in coke as delivered is a common occurrence, instead of the figure of about 5 per cent. generally mentioned. This means a heavy drop in net efficiency, though gasworks coke, when reasonably dry, is an excellent fuel

[1] G. A. Hebden, "Comparative Survey of Coke-Oven Practice in Various Countries," *Empire Mining and Metallurgical Congress*, June 3–6, 1924.

[2] Smokeless Fuel Conference, held in Sheffield on November 20, 1925, under the auspices of the Society of Chemical Industry (Chemical Engineering Group and Yorkshire Section), Institution of Chemical Engineers, Institution of Gas Engineers, and the Midland Institute of Mining Engineers.

for cylindrical steam boilers when used on the right lines and a moderate rate of combustion is not exceeded. Most of these troubles are due to poor structure, and one of the obvious remedies is to blend the coals so as to give a more dense, small-celled and chemically reactive product.

At the Sheffield Gas Coke Conference it was generally agreed that, by blending, considerable improvements could be made in reducing the plastic condition of many strongly swelling gas coals, using either non-coking coals or coke breeze, and H. Hollings gave some interesting results of trials carried out on a large scale at the works of the Gas Light and Coke Company. He found that with certain Durham coals, carbonised in continuous vertical retorts, the throughput was not good, but if this coal were blended with a non-caking coal and briquetted with a pitch binder before carbonisation, the throughput of the retorts was increased by 30 to 40 per cent. Further, a given Yorkshire gas coal was improved in throughput 30 to 35 per cent. by blending with non-coking coal.

Similar experiments have been made by W. C. Butterworth [1] of the Platteville Gas Company, Wisconsin, U.S.A., and exact figures are given of the yields from different blends of coals carried out over a period of seven months. The result was a considerable improvement in the quality of the coke, and a reduction in costs of production by suitable blending of the coals according to the circumstances. Of two coals from Illinois No. 6 Seam and Harlan Seam, the latter alone gave 1173 lbs. coke with 9973 cubic feet of standard gas per ton (2000 lbs.), and the net cost of the gas production was \$0.4426 per 1000 cubic feet. As regards gas production, the best results were obtained with a blend of 60 per cent. Illinois No. 6 and 40 per cent. Harlan Seam, which gave per ton 1027 lbs. of coke and 9779 cubic feet of gas, costing \$0.4171 per 1000, but the highest "balance" was a 50 : 50 mixture, giving 1053 lbs. of coke and 9870 cubic feet of gas, costing \$0.4182.

[1] W. C. Butterworth, "Mixed Coal Experiments," *Gas Age Record*, 1921, March 9, p. 11.

4. The Use of High-Temperature Carbonisation Coke Breeze instead of Non-Swelling Coals for Blending with Strongly Swelling Coal.

For the purpose of blending with a strongly swelling coal one of the most suitable products, almost entirely devoid of any resinous material, is high-temperature carbonisation coke breeze from gasworks and coke-ovens, which is a cheap fuel, practically a waste product, itself of comparatively good heating value, contains only a 1 to 2 per cent. volatile content, and is from many points of view an ideal absorbent for the excess of resinous material both as regards structure and chemical composition.

Like most ideas in connection with carbonisation the principle of using coke breeze to mix with coal is of ancient origin. The first mention of it seems to have been about sixty-five years ago in connection with the work of Joseph Souquière,[1] a civil engineer of Paris. His main object was to alter the properties of gasworks coke so as to make it a more generally applicable fuel, a problem still unsolved to-day. He pointed out that attempts to use coke by mixing it with "bituminous matters" and compressing it into blocks are of no use for high-temperature work because the material melts and runs, and he proposed to get over this difficulty by using raw coal instead. The patent states:

"The method of agglomeration comprised in this improved arrangement consists in pulverising the coke produced by any of the known processes and mixing it with various proportions of pounded coal of the same or different kind as that from which the coke has been produced. This mixture is then heated either in the distilling apparatus originally used for making the coke, or in a separate apparatus, and thus new coke is obtained, composed of one part coke twice distilled and another part coke which has been once distilled; the coke twice distilled being always of greater density than that only once treated."

The essential novelty of the patent was claimed to be the idea of grinding the coke before mixing it with the coal. Souquière also mentioned that much inferior coal could be utilised in this way by blending it with coke so as to produce a high-grade coke, and

[1] British Patent 1091, 1859.

that a much larger volume of gas was obtained by the carbonisation of such blended mixtures, besides giving coke of a greater density and coherence. He likewise noted that the charge shrank in volume during the heating, but the significance of this discovery as applied to low-temperature carbonisation was not realised, and the idea was allowed to lapse for over half a century.

To-day coke breeze for blending is a matter of practical interest chiefly in connection with low-temperature carbonisation, although there is no doubt that metallurgical coke breeze could be worked off by blending with suitable qualities of coal before high-temperature coking.

Parr and Olin[1] studied very carefully the principle of blending swelling bituminous coals with coke breeze. For example, Fig. 6 (Plate XXXII.) is a typical hard, close-grained, good quality low-temperature carbonisation fuel obtained from a blend of one part of "Majestic" (Illinois) coal and one part of gasworks coke, both ground equivalent to all through a 50-mesh screen. Fig. 7 represents the product from the low-temperature carbonisation at 842° to 932° F. (450° to 500° C.) of a blend of one part of Danville Mine (Illinois) coal and three parts of high-temperature carbonisation coke from this coal, ground equivalent to all through a 20-mesh screen, and made into a temporary briquette with molasses, this fuel having a crushing strain of 550 lbs. per square inch. They show that in many cases as much as 75 per cent. of coke breeze can be used with some of the most strongly swelling bituminous coals.

This application of coke breeze to blending with coal has subsequently been studied by other investigators. For example, Edgar C. Evans,[2] in 1917–1918, at Llwynipia, South Wales, carried out a research on the structure of coke, low-temperature fuel, and charcoal.

The coal used in the experiments was No. 2 Rhondda, a South Wales coal with a high resinous content and of a strongly swelling character, and Fig. 8A (Plate XXXIII.) shows a sample of this coal carbonised at 662° F. (350° C.). It is a characteristic low-temperature fuel, extraordinarily porous and friable. The other two samples (Fig, 8, B and C) are low-temperature fuels carbonised for two hours at 1022° to 1112° F. (550° to 600° C.) from

[1] See *ante*, p. 239.

[2] See *ante*, p. 240.

the same coal, but mixed with a gradually increasing amount of coke breeze. These fine photographs show clearly how the product becomes less and less porous as the percentage of coke breeze increases, until in the third sample the fuel is almost homogeneous, with only a very small area of porosity in the centre, a striking difference from the original raw coal.

T. Biddulph Smith [1] points out that if coke breeze or other inert material is blended with coking coal so as to absorb any excess of binding constituent, it is better to heat the charge to a higher temperature than normal, say 2372° F. (1300° C.), instead of 1832° F. (1000° C.), using a silica brick oven. This will give a coke equal to that obtained from an ordinary high-grade coking coal at 1832° F. (1000° C.), although the difficulties of the process in general are the comparatively fine grinding and intimate mixing necessary.

T. Biddulph Smith [2] has also referred to blending experiments as applied to a particular high-grade bituminous coal. At 1832° F. (1000° C.) this gave a good coke, but at 2192° F. (1200° C.) the product was inferior, because of excess of resinous content. When blended, however, with 20 per cent. of coke breeze and then carbonised at 2192° F. (1200° C.), the result was an extremely high-grade coke.

Further, John Roberts [3] states that one considerable advantage of blending is that the heat conductivity of the mixture is considerably increased as compared with the swelling coal alone, an important point for low-temperature carbonisation. He gives a series of curves showing the rate of heat transmission in the case of a Welsh bituminous coal as compared with curves for blends with 20 per cent. and 30 per cent. of coke breeze. Under identical conditions of experiment in large crucibles he found that with the raw coal it took 57½ minutes for the centre of the charge to reach 680° F. (360° C.), whereas a 20 per cent. breeze blend only required 45½ minutes, and a 30 per cent. blend 31 minutes. This is stated to be due to the fact that the viscous stage of the charge represents very bad heat conductivity, and

[1] T. Biddulph Smith, "Application of American Practice to the British Coke Industry," *Cleveland Institution of Engineers*, December 7, 1924.

[2] T. Biddulph Smith, *Smokeless Fuel Conference, Sheffield*, November 20, 1925.

[3] John Roberts, "The Carbonisation of Coal at Low Temperature," *Transactions of the Institution of Mining Engineers*, 1921, vol. lxii.

the effect of blending with coke breeze or any other similar material is to reduce this viscous barrier to a minimum and thus maintain a relatively high rate of heat transmission throughout the whole period of carbonisation.

The structure of the three fuels mentioned is given in Fig. 9 (Plate XXXIII.), in which (A) is the residual low-temperature fuel from the raw coal, (B) that from the 20 per cent. breeze mixture, and (C) the 30 per cent. breeze mixture. It will be seen that the porosity of the fuel diminishes rapidly as the coke breeze content is increased. In general, Roberts suggests the manufacture of a free-burning smokeless fuel from coal blended in this way with coke breeze at a higher temperature than usual, about 1112° to 1400° F. (600° to 760° C.), using, if necessary for the purpose, the ordinary coke-oven plant, while also non-swelling coals, oxidised coals, or other products can be used as the inert material.

E. V. Evans,[1] of the South Metropolitan Gas Company, London, has blended gas coals with coke breeze, followed by briquetting at high pressures without a binder before carbonisation in gasworks retorts, so as to obtain a much superior quality of coke.

Although, in general, blending with coke breeze has a number of obvious advantages, the practice has one disadvantage compared with other blending methods. This is the fact that the breeze is an inert material and gives no by-products, thereby occupying the handling plant and ovens or retorts and taking heat twice over, and reducing the net throughput. Also for very high resinous coals, the amount of breeze required may be 50 per cent., in which case these objections become a serious matter, but as against this a low-grade material is being converted into a high-grade product.

5. The Blending of Swelling Coals with Low-Temperature Carbonisation Fuels.

As already indicated, this subject is of particular interest to the iron and steel industries because of the work now being carried out in the Saar district to render the high swelling coals of that region suitable for the production of good grade metal-

[1] E. V. Evans, "A Study of the Destructive Distillation of Coal," *Cantor Lectures, Royal Society of Arts* (London), February 25, March 3 and 10, 1924.

lurgical coke by submitting part of the coal to low-temperature carbonisation and using the resulting fuel for blending. Similar work is also being undertaken in the United States. From the national point of view, however, the principle has the disadvantage of not utilising non-coking coal, and therefore causing the supply of special swelling coals to be used up faster than ever. As against this, in many areas non-swelling coals can be used for low-temperature carbonisation to provide the inert material, and this general principle is of particular importance to a number of those processes.

Parr and Olin[1] have shown clearly that the most strongly swelling bituminous coal can be blended with low-temperature fuels from the same or any other coal, so as to give on simple carbonisation at 752° to 932° F. (400° to 500° C.) a hard and dense fuel, entirely different from the soft and spongy product obtained from the coal alone. In some of these experiments all the different low-temperature fuels that had accumulated in the laboratory were ground up together, giving a product that had the following analysis :

	Per Cent.
Fixed carbon	66·40
Volatile matter	19·85
Ash	11·90
Moisture	1·85
	100·00
Sulphur	2·62
B.Th.U. per lb.	11,243

The pulverised material was then mixed in any suitable proportion in a ball mill with the crushed coal. As a typical example of many results, a given swelling Illinois coal, "Vermillion County," when carbonised at 752° to 932° F. (400° to 500° C.), gives a very porous fuel, shown in Fig. 10 (Plate XXXIV.), having a specific gravity of 0·650. If, however, two parts of this "Vermillion County" coal are blended with one part of the low-temperature breeze, the resulting product, carbonised in exactly the same way, becomes dense and non-porous, as shown in Fig. 11, with a specific gravity of 0·848. Similarly, a blend of 50 : 50 Vermillion County product from coal and low-temperature breeze has a specific gravity of 0·852.

[1] See *ante*, p. 237.

The improvement in the quality of metallurgical coke by blending with swelling coals, low-temperature fuels, or submitting part of the coal itself to a preliminary low-temperature carbonisation, is also described by G. Charpy and M. Godchot.[1]

With regard to the Saar, E. Trasenster[2] states that the principle hitherto generally adopted with a particular variety of Saar coal, having 31 to 34 per cent. volatile matter, was to blend it with 10 to 25 per cent. of coals having much less volatile content brought from outside sources, both the raw fuels being as a rule in a highly pulverised condition and intimately mixed, as already described, although in some cases the coals are merely crushed. To-day the more scientific practice is to submit part of the Saar coal to low-temperature carbonisation in long, continuous, cylindrical rotary retorts at about 842° to 878° F. (450° to 570° C.), this plant now being large enough to supply the non-coking portion of the blend for thirty coke-ovens. The coke obtained on these lines by blending with low-temperature carbonisation fuels from the same coal is of an extremely high-grade quality, while the rich gas and oils from the low-temperature carbonisation retorts are collected separately.

Also, in Germany F. Fischer and W. Krönig[3] have dealt with the low-temperature carbonisation of a blended mixture of low-temperature fuel and swelling bituminous coal. Excellent results are stated to be obtained, the density of the final fuel increasing as the two constituents are ground finer and finer, while the rate of the heating also plays a part in the matter.

6. Application to Blending of Oxidised or Preheated Coals, in which the Swelling Properties are Entirely Destroyed and the Product then Used for Mixing.

Another general method of blending to which considerable attention has been given in connection with various processes of carbonisation is to add to the swelling bituminous coal a certain proportion of coal whose coking properties have been destroyed by oxidation.

[1] See *ante*, p. 240.
[2] E. Trasenster, *Revue Universelle des Mines*, February 1, 1925.
[3] F. Fischer and W. Krönig, "Increasing the Density of Semi-Coke without Applying Pressure," *Brennstoff Chemie*, 1924, p. 301.

It has of course been known for a very long time, probably over a century, that raw coal absorbs oxygen from the air, in some cases with such readiness as to cause spontaneous heating and combustion of coal dumps. Apparently the first detailed scientific investigations on the subject were made by Grundmann [1] of Tarnovitz, who showed that a pile of 300 tons of coal exposed to the weather lost 58 per cent. by weight in nine months. Also at this time Reder (1865), the well-known chemist Varrentrap (1865), and other workers in Germany came to the conclusion that the weathering of coal is due to the absorption of oxygen. Richter [2] investigated particularly the effect of altering the size of the coal particles, the moisture content, the temperature, and various other factors which alter the rate of oxidation. It is also common knowledge from practical experience that many qualities of coal should be used at once in the coke-ovens as soon as they come up from the mine, as, if left lying about, both the yield of the by-products and the quality of the coal suffer. Thus in one particular coal and ironworks in Great Britain to-day it is calculated that two or three days' exposure of a 30 per cent. volatile coal as freshly mined reduces it to 28 to 29 per cent.

As long ago as 1875 John Percy showed that with normal coking conditions a certain South Staffordshire non-coking coal gave an extremely friable and poor product, but if it were very rapidly heated, care being exercised to exclude all air, then a good grade coke was obtained, the reason being that the oxidation and destruction of the binding material was reduced to a considerable extent.

The modern principle of using narrow coke-ovens and heating the charge as rapidly as possible, combined with the highest temperature of carbonisation through the use of silica bricks, is therefore only a practical application of the knowledge of half a century ago.

Again, M. de Marsilly [3] states that certain qualities of strongly coking coals lose their coking properties when they have been exposed to the air for six months, while Percy [4] mentions the case

[1] *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, 1867.
[2] *Proceedings of the German Gas Association*, 1868.
[3] *Comptes Rendus*, 1858, p. 882. [4] "Metallurgy," 1861.

of a coal at Penclawdd, near Swansea, which actually lost its coking properties entirely after exposure to the air for only one to two days.

Haedicke, in 1880, showed that iron pyrites are not the only cause of the rise in temperature and spontaneous combustion of coal, and other workers on the subject are Durand,[1] Jackson,[2] Sohren,[3] Vivian B. Lewes, Haberman,[4] Boudouard,[5] and Dennstedt and Bunz.[6]

Then, again, Parr[7] and his associates have fully studied the subject, and considerable reference is made to the loss of coking properties of coals by the action of oxygen not only on weathering, but in the retort itself on carbonisation.

A. Douglas[8] has also carried out a number of experiments on the effect of oxygen on coal in connection with high-temperature carbonisation.

Other more recent contributions to the deterioration of coking coals by storage and absorption of oxygen are those of W. Seymour,[9] G. Coles and J. Ivon Graham,[10] J. F. Bryne and J. D. Davis,[11] and Marie C. Stopes and R. V. Wheeler.[12]

Further, it has been shown by Mahler and Charion[13] that when raw coal is in a very finely pulverised condition the action of air below 212° F. (100° C.) results in an appreciable decomposition, water, CO_2, and CO being given off; while at 257° F. (125° C.) water of constitution is evolved, and above 302° F. (150° C.) a large number of organic compounds begin to form, including acetic acid, acetones, aldehydes, and methyl alcohol. F. S. Sinnatt[14] has also pointed out that when a strongly swelling Lancashire bituminous coal is finely pulverised and allowed to

[1] *Journal of the American Chemical Society*, December 1900 and July 1904.
[2] *Engineering and Mining Journal*, July 14, 1906.
[3] *Gas World*, April 13, 1901.
[4] *Schillings Journal für Gasbeleuchtung*, 1906.
[5] *Bulletin de la Société Chimique*, 1905, No. 5, Series 4, p. 365.
[6] *Zeitscrift für angewandte Chemie*, 1908, No. 21, p. 1085.
[7] *University of Illinois Bulletins, Nos.* 17 (1907), 38 (1909), 46 (1910), 97 (1917).
[8] *Gas World*, October 5, 1912, p. 415.
[9] *Blast-Furnace and Steel Plant*, Pittsburgh, 1921, vol. ix. p. 435.
[10] *Fuel*, 1924, p. 384.
[11] *Industrial and Engineering Chemistry*, Washington, 1924, p. 775.
[12] "The Spontaneous Combustion of Coal," with Appendices by R. Lessing and F. W. Tideswell.
[13] *Comptes Rendus*, 1910, vol. cl. pp. 1521, 1604.
[14] *Fuel*, 1922, vol. i., No. 1.

FIG. 1.—Specimen of low-temperature carbonisation fuel from Williamson County, Ill., U.S.A. (*Bulletin* 79, *University of Illinois*, 1915.)

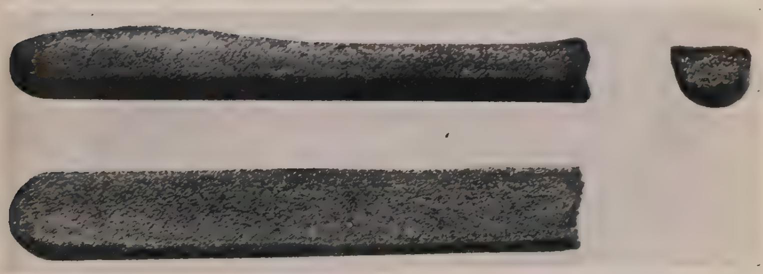


FIG. 2.—Specimens of low-temperature carbonisation fuel from Dalton Main non-swelling coal. (*Report of H.M. Fuel Research Board for* 1920-21.)

[*To face p.* 256

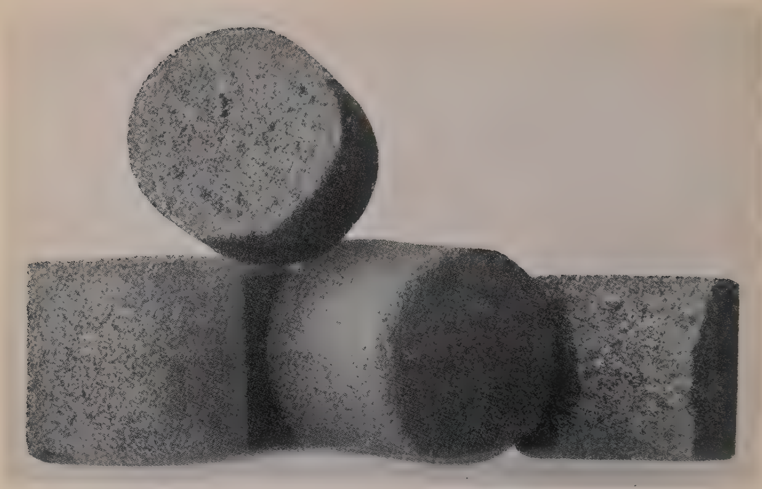


FIG. 3.—Specimens of low-temperature carbonisation fuel from a blend of one part of Illinois swelling coal and three parts of anthracite. (*Bulletin* 60, *University of Illinois*, 1912.)

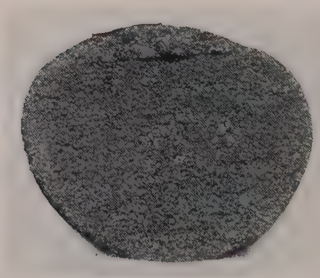
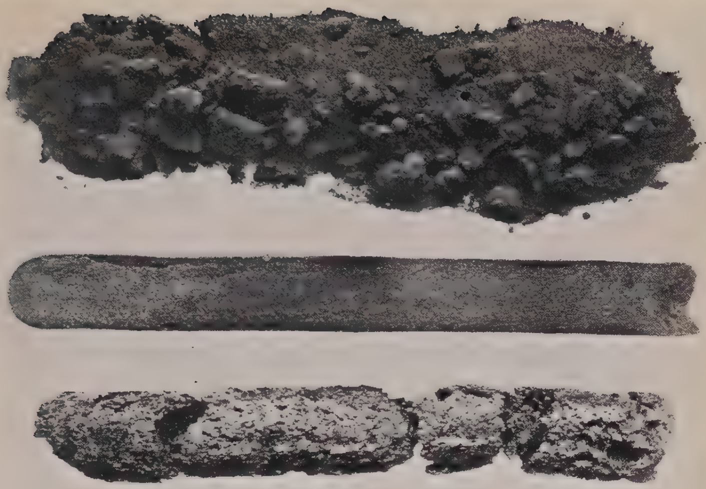


FIG. 4.—Specimen of low-temperature fuel from a blend of strongly swelling No. 2 Rhondda coal with a high volatile but non-swelling coal. (*Procs. S. Wales Inst. of Engineers*, 1922.)



A

B

C

FIG. 5.—Specimens of low-temperature fuel (B) from a blend of 60 per cent. Mitchell Main coal and 40 per cent. non-swelling Ellistown Main, showing also the typical non-coking products of different character obtained respectively when Mitchell Main coal (C) and Ellistown coal (A) are carbonised separately. (*Report of H.M. Fuel Research Board*, 1920-21.)

FIG. 6.—Specimens of low-temperature carbonisation fuel from a blend of one part of Majestic (Illinois) swelling coal and one part of gasworks coke. (*Bulletin* 60, *University of Illinois*, 1912.)

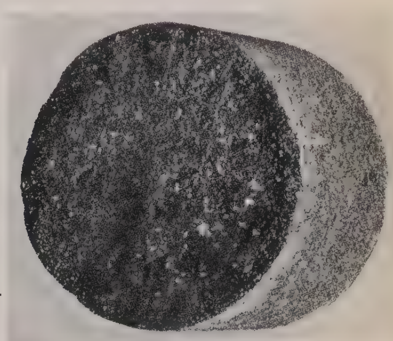
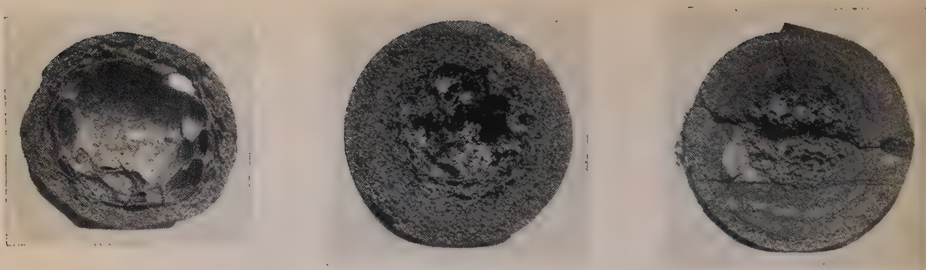
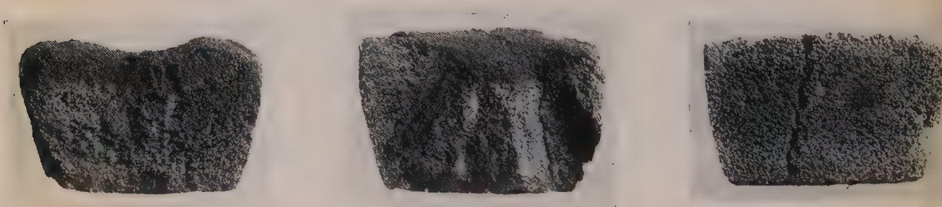


FIG. 7.—Specimen of low-temperature carbonisation fuel from a blend of one part of Danville (Illinois) swelling coal and three parts of gasworks coke. (*Bulletin* 60, *University of Illinois*, 1912.)



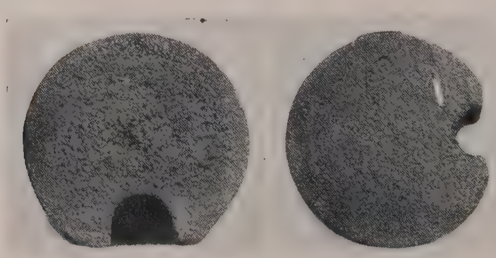
A B C

FIG. 8.—Specimens of low-temperature carbonisation of No. 2 Rhondda strongly swelling coal (A), and of different blends (B) and (C) with gasworks coke breeze. (*Procs. S. Wales Inst. of Engineers*, 1922.)



A B C

FIG. 9.—Partly carbonised charges of swelling Welsh coal under high-temperature conditions. (A) Untreated coal. (B) Blended with 20 per cent. coke breeze. (C) Blended with 30 per cent. coke breeze. (*Trans. Inst. of Mining Engineers*, 1921.)



A B

FIG. 12.—Specimens of low-temperature fuels from a blend of strongly swelling No. 2 Rhondda coal and the same coal after oxidation. (*Procs. S. Wales Inst. of Engineers*, 1923.)

FIG. 10.—Specimen of low-temperature fuel from strongly swelling Vermillion County (Illinois) coal. (*Bulletin* 79, *University of Illinois*, 1915.)

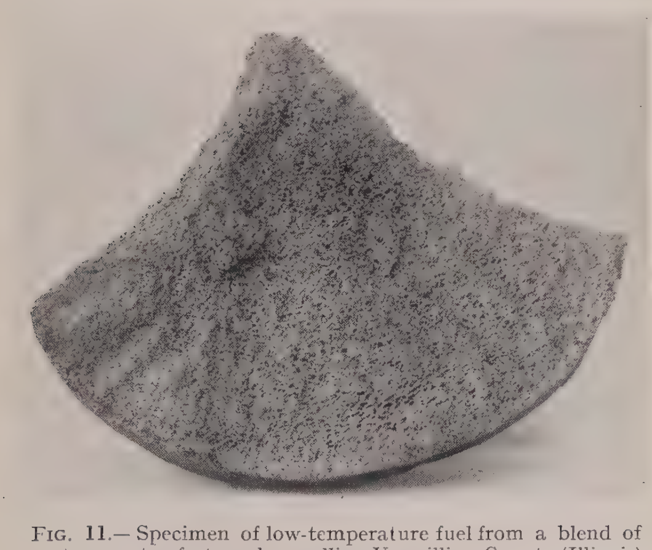


FIG. 11.— Specimen of low-temperature fuel from a blend of two parts of strongly swelling Vermillion County (Illinois) coal and one part of low-temperature fuel breeze. (*Bulletin* 79, *University of Illinois*, 1915.)

fall in an inert atmosphere through a zone heated to 788° F. (420° C.), it loses its coking power entirely in eighteen seconds.

It may be stated that the action of oxidising agents in general on coal has been known for much more than 100 years. Hatchett,[1] in 1805, studied the action of nitric acid on coal, and in 1879 E. Guignet[2] gave a description of the action of concentrated nitric acid on pulverised coal, generally for one hour at 230° F. (110° C.), when 4 per cent. became soluble in phenol, the residue being then treated further with nitric acid to destroy its coking properties. Also Cross and Bevan,[3] in their famous investigation on the subject of cellulose, showed that the action of hydrochloric acid and potassium perchlorate on coal gave chlorine compounds of a similar nature to those obtained in the same way from cellulose. The action of nitric acid on coal has likewise been studied by R. T. Friswell,[4] by Anderson and Roberts,[5] and by O. Boudouard.[6]

In connection with the oxidation of coal by chemical means, the results of some very interesting work on the action of silver bichromate and sulphuric acid on pulverised coal are given by L. J. Simon.[7] It is shown that if pulverised coal is heated at 212° F. (100° C.) with a mixture of silver bichromate and concentrated sulphuric acid, the oxidation and complete disintegration resulting seem to indicate that part of the intimately mixed coal substance is easily attacked, while the rest is much more difficult. Thus at 212° F. (100° C.) about 4 to 5 per cent. of the total carbon remains unoxidised, while at 140° F. (60° C.) about 28 per cent. remains. The gases given off in the decomposition of the coal substance are mostly CO_2; in one case, for example, a coal with 72·4 per cent. of carbon had 78 per cent. of this converted to CO_2, the rest being carbonaceous material, partly soluble and partly insoluble. Prolonged oxidation in this way also gives CO and oxygen in the gases.

It is not clear when oxidised coal was actually first used for blending to improve the general process of carbonisation, but

[1] *Philosophical Magazine*, 1805.
[2] *Comptes Rendus*, 1879, vol. lxxxviii. p. 590.
[3] *Philosophical Magazine*, 1882.
[4] *Proceedings of the Chemical Society*, 1892, vol. ix. p. 8.
[5] *Journal of the Society of Chemical Industry*, 1898, vol. xvii. p. 1013.
[6] *Bulletin de la Société Chimique*, 1909.
[7] *Comptes Rendus*, 1924, January 28, p. 495; February 25, p. 775.

it is very largely due to the work of S. W. Parr that oxidised coal to-day plays such an important part in a number of low-temperature carbonisation processes. In his earlier experiments, superheated steam was largely used to heat the charge, chiefly because air could be eliminated, as already indicated.

E. R. Sutcliffe and Edgar C. Evans [1] also give results of work carried out during 1917–1918 at the Rhondda Research Laboratories with the strongly swelling coal No. 2 Rhondda. In a number of cases the non-coking material used was a portion of the same coal which had been roughly pulverised and heated in an oxidising atmosphere to below its melting point, about 572° F. (300° C.), until the coking properties were completely destroyed. Chemical analysis showed that the volatile content remained as before, but the properties as regards carbonisation were entirely altered, and on being heated under ordinary low-temperature conditions, 932° to 1112° F. (500° to 600° C.), there was no sign of coking, and an actual contraction took place instead of the strong swelling.

This non-coking oxidised coal was then blended in various proportions with the No. 2 Rhondda, and the product heated for two hours in a closed externally heated retort at a temperature of 1022° to 1112° F. (550° to 600° C.). It will be remembered that the porous fuel from the No. 2 Rhondda coal itself—carbonised direct at 662° F. (350° C.)—is given in Fig. 8A (Plate XXXIII.). Fig. 12 (Plate XXXIII.) indicates the resulting low-temperature carbonisation fuels from a blend of the No. 2 Rhondda coal and the oxidised coal (A), showing an enormous improvement in the structure, with merely a very slight porosity in the centre, owing to having a shade too much of the swelling coal. In (B) the conditions are perfect, giving a hard, dense, and thoroughly uniform low-temperature fuel with just the right proportions of swelling coal and oxidised coals, and in fact it is possible to make a blend that contracts slightly.

John Roberts,[2] whose work has already been referred to, gives the case of a blend of fifty parts of "Silkstone Seam," a strongly swelling Yorkshire coal, and fifty parts of this "Silkstone

[1] "The Influence of Structure on the Combustibility and other Properties of Solid Fuels," *Journal of the Society of Chemical Industry*, June 30, 1922, vol. xli. p. 196 (Transactions); see *ante*, p. 250.

[2] British Patent 187336, 1921; see *ante*, p. 251.

Seam" coal that had had its coking properties destroyed by oxidation or preliminary heating. In order to carry out this latter operation the coal was roughly pulverised as usual, say, all through a 10-mesh screen, and was then heated for one to six hours at a temperature of from 212° to 662° F. (100° to 350° C.) in the presence of air, with subsequent cooling, the temperature and duration of the heating necessary to destroy the coking properties being dependent on the quality of the coal and the degree of grinding.

Finally, a remarkable new development in connection with the use of oxidised coal for carbonisation is included in the "Carbocite Dual Carbonisation" or "Wisner" process of low-temperature carbonisation, mentioned on p. 266.

7. The Use of Anthracite, Anthracitic Coals, and Non-Caking Coals in Coke Production by Blending with High- or Low-Temperature Tars, Pitch, or Oils, as well as Petroleum and other Natural Products.

Many investigators during the past seventy-five years have endeavoured to manufacture high-grade metallurgical coke by heating non-coking or very slightly coking coals blended with coal-tar, pitch, low-temperature oils, bitumens, petroleum oils, and similar liquid products to supply the deficiency of resinous or cementing material. In most cases anthracitic or definitely non-coking coal and coal-tar pitch, ground up to a powder, have been employed, the mixture being then used in the coke-ovens instead of ordinary coking coals. The obvious objection to the principle is of course the cost of the pitch or oils necessary, together with the somewhat erratic nature of the supply, for which reasons alone the method is to-day not of much importance, except in special cases, although if low-temperature carbonisation were adopted on an extensive scale conditions in both these respects might be different. But there is no question that under proper conditions, and apart from the practical considerations mentioned, a good grade metallurgical coke can be made from a blend of non-coking coals and pitch, tar, high boiling-point petroleum fractions, and similar products. Some considerable difference of

opinion exists, however, as to how this general principle should be applied in practice.

Thus Dr. A. Thau [1] states that if metallurgical coke is made from a low-grade coking or non-coking coal mixed with a granulated hard pitch, the coke is very friable, while if liquid tar is used the coke is too hard. The best method, therefore, would appear to be to dry the coal, pulverise it, and then grind up intimately with liquid tar.

One of the first men to apply this general principle of blending on a large scale was John Bethell,[2] who patented the manufacture of metallurgical coke from a blend of coal and coal-tar pitch, using 4 tons of coal and 1 ton of pitch; while John Percy also states that he had himself carried out laboratory experiments before the work of Bethell in the production of carbon crucibles from blended mixtures of gasworks tar and anthracite dust or coke dust. Bethell [3] also had a second patent for carbonising in a coke-oven a mixture of pitch and coke breeze, so as to convert the latter into large pieces of fuel and thus improve the value.

Many other inventors after John Bethell endeavoured to use blends of tar and pitch with coal for the production of metallurgical coke. Thus in 1857 William Cory [4] employed a mixture of anthracite and non-caking coal, intimately mixed with one-fifth to one-tenth of the weight of gas-tar or pitch, and in 1858 J. T. Smith [5] took out a patent for using blends of small coal, tar, and pitch. There is also a patent of Jabez Church [6] relating to the addition of lime or limestone to a blend of pitch or coal-tar, with coal and coke breeze, and incidentally it is curious to note the very large number of patents in the history of carbonisation that mention the addition of mineral matter of every description to coal or other carbonaceous material with a view to improving either the coke or the gas and other by-products.

After this period there was apparently a slump in the idea of the use of pitch and tar for blending, but in 1883 Henry Clay Bull of Brooklyn, New York, suggested making gas in ordinary gasworks retorts by carbonising at high temperatures a mixture

[1] "Methods for Improving the Quality of Coke," *Stahl und Eisen*, 1923, vol. xliii. p. 1127.

[2] British Patent 80, 1854.

[3] British Patent 159, 1858.

[4] British Patent 1174, 1857.

[5] British Patent 1614, 1858.

[6] British Patent 784, 1860.

of pulverised coal, coal-tar, and lime, which was stated to have the advantages of giving a gas free from sulphur compounds and a coke of great strength, resembling the metallurgical qualities, and quite different from soft gasworks coke.

Hempel and Lierg[1] claimed to have demonstrated that good quality metallurgical coke could be produced from almost any quality coal by blending with tar, pitch, clay, and metallurgical coke, and they gave a case of a coal, with 4·9 per cent. of ash, producing a residue which could be crumpled between the fingers. A very good metallurgical coke, however, was stated to be made from a blend of 120 parts of the coal, 18 parts of coke prepared from this coal, 4·8 parts of clay, and 8 parts of pitch dissolved in 18 parts of tar. The product was of the best quality, with a crushing strain of 5600 lbs. per square inch, as compared with 2050 to 2600 lbs. for ordinary metallurgical coke.

A. Douglas,[2] in connection with his experiments on coal blending already mentioned, tried the effect of adding pitch to poor quality coking coals. The results were conflicting, but his conclusion was that, in many cases a slightly coking coal could be made in this way to give a good quality metallurgical coke.

The principle of blending non-coking coals with finely divided pitch, so as to give a mixture suitable for the production of metallurgical coke, has also been investigated by Joseph Becker,[3] the amount of pitch used, however, not being stated. In this process the non-coking coal and the solid pitch are crushed or pulverised separately, and the two are then thoroughly mixed and coked as usual, after stamping down, in the ordinary coke-ovens. The final mixture should, however, contain about 10 per cent. of moisture, and if this is not already present the necessary additional water is added, whilst coal-tar, oil residues, and similar products may also be employed.

The most interesting modern work, however, in connection with the production of metallurgical coke from non-coking coals blended with pitch and similar products is that of Donald Markle.[4]

[1] *Gas Journal*, 1911, p. 822.

[2] See *ante*, p. 240.

[3] American Patent 1182738, 1916.

[4] "Anthracoal. A New Domestic and Metallurgical Fuel made by Coking Anthracite Fines with Coal-Tar Pitch," *American Institute of Mining and Metallurgical Engineers*, September 12, 1921. American Patent 1407709, 1922.

This work was carried out first in the laboratory of the Lehigh University, with the object of endeavouring to find a profitable outlet for small anthracite, and latterly on a large scale at a modern coke-oven plant at Syracuse; the coking period was nineteen hours. All kinds of blends were made, varying between the range of 14·8 to 25·0 per cent., while two different grades of pitch were also employed. In general, the best proportions are about 17 per cent. of pitch, ground to a powder, and 83 per cent. of fine anthracite, the latter being dried and ground to a fineness equivalent to all through a $\frac{3}{64}$-inch round mesh. If too much pitch is used, apart from the difficulties mentioned, the coke becomes porous and there is a carbon scale, while discharging becomes difficult, the excess of pitch always having a tendency to pass to the sides of the charge. With less than 15 per cent. of pitch the product is not of sufficient strength.

The special coke is known as "Anthracoal," and is claimed to be of the highest quality, being harder, tougher, and stronger than ordinary coke, constituting a dense and homogeneous fuel, in colour varying from silvery to greyish black. Also it does not give much breeze, remaining in masses when discharged from the oven, and breaking with an irregular fracture, more like anthracite, while the carbonisation is complete in seventeen hours instead of nineteen as with coal. The analyses of two samples of the fuel show the following figures without washing the raw coal:

	Per Cent.	Per Cent.
Fixed carbon	82·59	83·25
Volatile matter	0·27	0·77
Ash	16·48	16·48
Moisture	0·10	0·17

If, however, the small anthracite with 35 per cent. ash is washed down to 9 per cent. the anthracoal has 90 per cent. of fixed carbon, 8½ per cent. of ash, and a heat value of 13,350 B.Th.U. per lb.

As regards the yields obtained by the high-temperature carbonisation of a blend of anthracite and pitch, the coke obtained is generally about 87 per cent. with normal quality of coal and a blend of 17:83. The total volatile matter is about 13·75 per cent., so that the yield of by-products is naturally much less

than a 28 to 35 per cent. coking coal. The average figures per American ton (2000 lbs.) of the blend are:

(1) Gas	5240 cubic feet (336 B.Th.U.).
(2) Light oils	0·6 gallon.
(3) Tar (dry above 338° F., 170° C.) .	5·07 gallons.
(4) Sulphate of ammonia. . .	9·9 lbs.
(5) Solid residue (anthracoal) . .	1740 lbs. (87 per cent.).

8. Blending in the Brown Coal and Lignite Carbonisation Industries.

The principle of blending has not been much used in the carbonisation of brown coal and lignite in Germany, where of course the industry is very old established, and apparently not much work has been done in other lignite-producing countries, such as Canada, Australia, and the United States, particularly North Dakota. Presumably the reason is the low value of the raw fuel and the fact that blending is not of much assistance in improving the quality of the product. Whether other carbonaceous materials could be utilised remains to be seen, and in this connection it may be mentioned that some considerable work has been carried out in Germany on the carbonisation of mixtures of brown coal and anthracite, an interesting contribution on the subject being that of A. Viehoff and E. Czako.[1]

The general conclusions were, however, that there was no advantage to be gained from blending either as regards lignite or anthracite. It is possible, however, in connection with the new German "Delkeskamp" process (see p. 266), involving briquetting with a colloidal binder, that brown coal and lignite blending will be utilised, since much work in this connection has been undertaken with blends of brown coal, lignite, and peat, as well as on the use of these materials in preparing the binder for ordinary coals.

9. Shale Blending.

In the same way, and probably for identical reasons, little seems to have been done as regards blending in the long history

[1] "Orientierende Versuche über die Entgasung von Braunkohle nnd Braunkohle-Steinkohle-Mischungen," *Journal für Gasbeleuchtung und Wasserversorgung,* June 12, 1920, p. 279.

of the carbonisation of shale. Victor C. Alderson[1] mentions, however, that some Colorado shales begin to stick in the retort when the temperature of carbonisation exceeds 850° F. (455° C.). Certain Nevada and Utah shales do not give this trouble even at 1200° F. (650° C.), and accordingly these may be blended with the Colorado shale to give a product that does not stick. Again, the very rich black Parachute Creek shale of Grand Valley, Colorado, becomes viscous at 850° F. (455° C.), but if blended with poorer quality shale (35 to 40 gallons of oil per ton) in the proportion of only 100 lbs. to 400 lbs. of Parachute shale the mixed product can be carbonised at 1000° F. (540° C.) without difficulty.

10. Chemical Methods in Blending.

Another aspect of the blending principle which may have remarkable possibilities in connection with the carbonisation and general treatment of raw coal is what may be called, for want of a better term, "chemical blending"; that is to say, coal or any other carbonaceous material, instead of being mixed in the ordinary way with other raw materials, may be blended with fuel products that have first been treated chemically. Also chemical compounds may be blended with the fuels so as to affect the carbonisation, and it is rather surprising that this general line of research has not attracted more attention.

One example of the first principle is in connection with the "Wallace" process of carbonisation in the United States, which consists essentially in the use of a vertical, intermittent, externally heated metal retort having an internal perforated pipe of wide diameter through the middle of the charge for the rapid withdrawal of the gases and vapours. Highly bituminous coking coal is extracted with tar acid vapours at the boiling point, not over 450° F. (230° C.), as separated from low-temperature tar. A considerable amount of bituminous material is thereby dissolved out of the coal on well-known lines which seems to be mainly the coking constituent, since it puffs up in a remarkable manner when heated, whilst the residual coal no longer has coking properties. If now this dissolved material be blended with a

[1] "The Oil Shale Industry."

non-coking coal, the result is stated to be an excellent coking mixture.

As regards the addition of definite chemical compounds to a fuel blend, the "Fuelite" process of Walter W. Strafford,[1] of London, is an interesting example. The principle is that of blending caking and non-caking coals in a fine state of division with the aid of an emulsion of water and soft soap or creosote, and then carbonising the product either at low or high temperatures. Generally about 80 to 90 per cent. of non-caking coal and 10 to 20 per cent. of caking coal are used, depending on the coking index, and the grinding is equivalent to all through a $\frac{1}{10}$-inch mesh, or less. The final emulsified mixture contains only about 10 to 15 per cent. of water and is stamped down in the retort or oven, the temperature of carbonisation being either about 1112° F. (600° C.) or 2192° F. (1200° C.), according to the quality of the fuel required.

It is claimed that the product is different from any ordinary low- or high-temperature cokes, being free-burning, dense, and hard, while by suitable modifications either smokeless household fuel or metallurgical coke can be obtained from the same plant. The reason is stated to be the extremely intimate mixture of the non-coking and coking coal, because of the emulsification, with an unusually even distribution of the resinous matter. Under the second patent barium carbonate is added, generally along with charcoal, to the blended pulverised coals or other material, including coke breeze, with some tar to bind the mass together, the latter, of course, being in this respect similar to the methods of Section 7. The main claim is that barium salts, and especially the carbonate, have some catalytic action which accelerates the coking process and gives a superior residual fuel. For example, it is stated that at high-temperature carbonisation up to 1832° F. (1000° C.) the resulting product is free-burning and quite different from ordinary metallurgical coke. Of course the addition of mineral salts in general to improve carbonisation processes, especially the tar and the gas, is of very ancient origin, and common salt, potassium chloride, and lime have often been tried during the past sixty or seventy years.

Under this heading may also be mentioned the work of John

[1] British Patents 221526, 1923, and 176882, 1920.

C. Jolly and Professor R. V. Wheeler,[1] although as a rule coals only are blended together. The principle is essentially to add to the coking coal in the metallurgical coke-oven process some material which at temperatures of 752° to 1112° F. (400° to 600° C.) will give off a high proportion of hydrogen, carbon monoxide, or other reducing gas, at the same time leaving an inert residue that will not affect the quality of the coke. The idea is that these reducing gases reduce the amount of sulphur in the final coke, and generally the material used is anthracite or semi-anthracitic coal, which on high-temperature carbonisation gives off a considerable proportion of hydrogen in the gases.

11. A Brief Reference to a Number of Typical Low-Temperature Carbonisation Processes of Special Interest to the Iron and Steel Industries, and in which Blending in General Plays an Important Part.

(1) "*Carbocite Dual Carbonisation*" or "*Wisner*" *Process* (invention of Clarence B. Wisner, Canton, Ohio, U.S.A.).—Crushed coals heated in a current of heated air up to 300° F. (150° C.) ("thermodised"), generally for 30 to 45 minutes in a long, mechanically continuous, cylindrical, rotary retort, externally heated to 600° F. (315° C.), and then either directly carbonised at 900° F. (480° C.) in a similar type of externally heated rotary retort to give a hard smokeless fuel direct, or passed to coke-ovens.

(2) "*Coalite*" *Process* (Low-Temperature Carbonisation, Ltd., London, based on original work of Thomas Parker).—Carbonisation at 1000° F. (500° C.) for 6 to 8 hours in simple, intermittent, vertical, externally heated retorts, generally of cast-iron, so that the swelling viscous material gives a compression to the charge and results in a dense, hard, smokeless fuel.

(3) *Delkeskamp Process* (invention of Dr. Rudolph Delkeskamp of Berlin).—Coals or any carbonaceous materials are briquetted at ordinary pressures, using only as a binder part of the charge itself, ground with water to a colloidal condition. Claims to give thereby an intensely hard

[1] British Patent 236002, 1925.

briquette available for high- or low-temperature carbonisation without softening or swelling, eliminating pitch or abnormally high-pressure briquetting. Also applicable to iron ore briquetting for blast-furnaces.

(4) *Dobbelstein Process* (Otto Dobbelstein, Essen, Germany).—Mechanically continuous production of hard, smokeless, low-temperature fuel with carbonisation at about 1022° F. (550° C.) for 4 hours, using a special, horizontal, cylindrical rotary retort built up of alternate transverse thin steel cells 2 to 3 inches wide and heating chambers 4 inches wide, with a loose internal roller and ram feed, giving compression of the viscous charge.

(5) *Fellner and Ziegler* ("*Allkog*") *Process* (Westphalia, Germany. Invention of Niels Young).—Long, rotary, slightly inclined, mechanically continuous, cylindrical retort, externally heated at about 932° F. (500° C.) for 3 to 3½ hours. Combined with recovery of light oils at very high pressures, up to 50 atmospheres, and production of "Gasol" for welding.

(6) "*Fusion*" *Retort Process* at Middlewich, Cheshire, of T. W. Stainer Hutchins.—Long, rotary, horizontal, mechanically continuous, externally heated, cylindrical retort, having inside loose "breakers" of boiler plate, with 3 to 8 projecting arms or blades which roll round and prevent deposition of hard deposits on the retort wall. Duration of heating about 2 hours, and temperature 850° F. (455° C.).

(7) "*Kohlenscheidungs Gesellschaft*" *Process* (Essen, Germany). (Matthias Stinnes I./II. Colliery, Karnap, near Essen).—Long, rotary, slightly inclined, mechanically continuous, rotary retort, built up of one cylinder inside another, giving a double travel. Direct production of hard smokeless fuel with 1¼ hours' heating at approximately 932° to 1022° F. (500° to 530° C.).

(8) *Maclaurin Process* (invention of Robert Maclaurin, Glasgow).—Vertical, mechanically continuous retort of great height, like a small blast-furnace, having a regulated supply of air and steam passed in at the bottom, part of charge being gasified to heat the rest on the internal principle. Total duration of travel of charge 30 hours, with maximum

temperature of 1472° F. (800° C.) in hottest zone, with production of hard smokeless fuel.

(9) *Midland Coal Products Process* (Colwick Estates, Nottingham).—Briquetting of small non-coking coals and some coking coal with pitch as usual, and carbonising the pitch briquettes in a vertical, mechanically continuous retort, using a blast of steam and air at the bottom to partially gasify the charge. Duration of travel 5 hours, and maximum temperature zone 2192° F. (1200° C.).

(10) *Nielsen* or "*L.N.*" *Process* (Harald Nielsen and Bryan Laing, London).—Mechanically continuous, long, rotary, slightly inclined cylindrical retort, with internal heating to about 1022° to 1202° F. (550° to 650° C.) at the hot end, using the sensible heat of producer or similar gas, which is passed through the reverse way to the travel of the charge. Duration of heating, 2½ hours.

(11) *Pure Coal Briquette Process* (E. R. Sutcliffe and Messrs. Leigh Smokeless Fuels, Ltd., Leigh, Lancashire).—Crushed coals blended with 10 to 15 per cent. coke breeze or other material and briquetted at very high pressures, 8 to 10 tons per square inch, without pitch or other binder, in a special press. The "pure coal briquettes" then carbonised in a vertical, mechanically continuous, internally heated retort, using steam and inert gases at 1600° to 1850° F. (870° to 1010° C.) during 6 to 8 hours.

(12) *Raffloer Process* (invention of E. Raffloer of Duisburg, Germany).—Mechanically continuous production of hard, smokeless, low-temperature fuel, with carbonisation at about 842° F. (500° C.) for 1 hour, using a special horizontal cylindrical rotary retort, externally heated, and divided inside into a series of long, parallel, narrow channels or gutters filled with the charge, operated with reciprocating rams, and also having a loose, heavy roller for compression of the viscous charge.

(13) *Smith* "*Carbocoal*" *Process* (New York. Charles Howard Smith, now being reorganised by C. V. McIntire).—Carbonisation for 2½ to 3 hours at 850° to 950° F. (455° to 510° C.) in mechanically continuous, externally heated, horizontal primary retorts, having an internal screw conveyor.

Briquetting of this low-temperature fuel with pitch, and carbonisation of the briquettes for 8 hours at 1800° F. (980° C.) in externally heated, intermittent, inclined firebrick retort.

(14) *Staveley Coal and Iron Co., Ltd., Chesterfield* (Mr. Charles Markham).—Mainly intended for canneloid colliery refuse. The chief work is the use of an intermittent, vertical, cast-iron retort, with charge ignited at the top, and a regulated current of steam and air drawn through downwards, giving a travelling zone of combustion. Also using exhaust of large gas-engine, at about 1000° F. (540° C.), as an internal heating medium.

(15) *Summers Continuous Coking Process* (L. L. Summers, New York).—A long, horizontal, externally heated, firebrick oven, with slightly arched top, having a reciprocating floor of heavy cast-iron sections operated by a hydraulic ram and provided with a vertical central plate or fin for part of the length which grips the charge. The latter passes through with intermittent forward motion at any desired temperature of carbonisation.

(16) *Tozer Process* (C. W. Tozer, London).—Similar in principle to "Coalite"; intermittent, vertical, externally heated cast-iron retort, but of special interior segmental construction, arranged as a double circle, giving eight compartments. The swelling viscous charge gives rise to internal compression, yielding a hard product, while the duration of the heating is generally 4 to $4\frac{1}{4}$ hours at 900° to 1000° F. (480° to 540° C.).

(17) *Thyssen Process* (Thyssen Maschinenfabrik A.G. of Mülheim-Ruhr, Germany).—Long, mechanically continuous, cylindrical, externally heated rotary retort, slightly inclined, with an inner spiral of narrow pitch to increase very much the travel of charge. Duration of heating $1\frac{1}{2}$ hours, and average temperature of carbonisation 932° F. (500° C.).

In conclusion, the author has to thank very sincerely, in addition to many of the different companies mentioned, the following gentlemen and firms for additional special assistance in connection with the compiling of this paper:—Mr. Edgar

C. Evans of the National Federation of Iron and Steel Manufacturers (London); Mr. Arthur Grounds of Messrs. Huntington, Heberlein & Co., Ltd.; Mr. Percy N. Hambly and the Coppée Company (Great Britain), Ltd. (London); Dr. Heinrich Koppers, the Koppers Coke-Oven Co. (Essen), and the Koppers Coke-Oven Co., Ltd. (Sheffield); Mr. Robert Maclaurin (Stirling); Messrs. Simon-Carvès, Ltd. (Manchester); Messrs. The Simplex Coke-Oven Co., Ltd. (Sheffield); Messrs. Société Générale de Fours à Coke Systèmes Lecocq (Brussels); Mr. L. L. Summers (New York); Dr. A. Thau (Halle, Saale, Germany); and Mr. Clarence B. Wisner (Carbocite Dual Carbonisation Corporation, Ohio).

DISCUSSION.

Dr. R. Lessing (London) said the paper came at a very opportune moment, because there could be no doubt that the question of blending coals had not received in the past that practical attention which it ought to have had. A good deal of scientific work had been done by, amongst others, Mr. Evans, who had proved, in conjunction with Mr. Sutcliffe, the advantages of combining in a suitable way the properties of swelling and non-swelling or coking and non-coking coals in the process of coking. One of the difficulties attending the problem was, in the first instance, that of geographical situation, for however desirable it might appear to mix in a suitable manner coals of different properties, there arose the practical, commercial and economic difficulty of how to get together two suitable constituents for one mixture without incurring expense for transport which was not commensurate with the advantages gained. At the same time, he had not the slightest doubt that if the coking properties of the various coals were studied from that point of view—if the minimum additions of one coal to another which were necessary to produce a certain result were found—then it would always be possible to carry the smaller proportion to the place of consumption or conversion of the larger one, or possibly—to come to the very attractive proposal of Dr. Koppers, to which the author had referred—of having large central coking installations into which the coal from the various sources would flow to be blended in the most scientific and most suitable manner.

Apart from the geographical and economic difficulty, there was the problem of the actual arrangements for making a suitable blend. They had in the past certainly dealt with blended coal mixtures, but what were considered blends, particularly by the coal exporter, would hardly stand scientific tests such as those to which the members had been listening. If a mixed cargo of several thousand tons of coals were made by simply pouring the contents of wagon A on to the top of wagon B, or by pouring the contents of three wagons containing one kind of coal on to the top of another wagon containing another kind of coal from a different colliery, those intimate mixtures which were necessary to produce proper results were not obtained. It was impossible for any one particular colliery, which could only contribute one of several components of a suitable blend, to make the necessary arrangements for proper blending, and it seemed reasonable, therefore, that the actual blending should be arranged for by co-operation between collieries, or by coke-ovens, which would have to be, of necessity, of considerable dimensions.

With regard to the export of British coal, blending was an absolutely essential corollary to the efficiency of that branch of the coal

industry; and in that respect it seemed that the duty of making arrangements for blending facilities would devolve on the railway companies or on the dock authorities. In the past, such facilities had not been available. Even facilities for the sampling of coals on really up-to-date, modern lines, had not been available to the extent which was desirable. The argument had been brought forward in the past that the railways objected to blending because it dislocated their traffic, but that appeared to him to be a comparatively small matter if so much were involved—and that a great deal in the coal trade was involved was shown by recent experience, even before the coal stoppage took place. Contracts which, in the past, had been given for British coal, had been definitely lost, not because the coals supplied were of bad quality—on the contrary, for many years some of the foreign buyers had stuck to the coal because of its inherent, well-known high quality (he was there referring particularly to gas coals)—but because foreigners had realised that a good many advantages were to be gained in carbonisation by blending, and were now going to countries where blending facilities were provided, and where they could obtain mixtures from which they could get definite results. In those mixtures the individual components might be actually inferior to the coal drawn in previous years from this country. For that reason alone it was very desirable that the subject of blending should obtain that practical support of the industry and of the coal trade which it deserved. The difficulties of blending had been overcome in other countries, particularly in Germany, the United States, and Belgium. In Germany, speaking more of the Ruhr than of the other districts, great advantage was taken of co-operation in the sale of the coal. The Ruhr Syndicate had absolute power to draw on the supplies of their members in any way and to any extent with reference to allocation which the management or their advisers thought fit. For that reason they had it in their power to direct suitable coals from their various collieries towards their central loading stations. The bulk of their export coal went to their harbours on the Rhine and flowed down in the same way that coal flowed down the Tyne from Durham and Northumberland and from the Welsh valleys towards Cardiff and Swansea. Under the control of the central selling authority the Germans had very fine shipping installations, and in that manner they could direct suitable qualities to be combined in blends as might be desired, and they did, in fact, study the requirements of their customers. Their constitution prohibited the selling, in the home traffic absolutely, and to a large extent in their foreign sales, of brands of coal; they sold coal by quality—by numbers—and were by that means able to get rid of even their inferior qualities (of which they had as much as, if not more than, any other coalfield in the world), in mixtures of acceptable value in which those inferior qualities were lost or obliterated. The Germans were thus very much better able to dispose of their coal completely, and at the same time to satisfy the consumer. That was largely due to the

organisation of their selling Syndicate, which not only had advantages in the actual selling, but reflected, of course, to a very large extent on the purely technical side of the collieries. The great development in German collieries, particularly in the Ruhr, was no doubt due to the fact that the colliery management was to-day entirely technical, and was completely relieved from the sales side, which was carried on by the Syndicate.

Professor H. Louis (Vice-President) said he desired to interject a word of caution, derived from his experience of a case where coal blending had not been a success. Some fifty years ago at the Landore Iron and Steel Works, Sir William Siemens conceived the idea of making a coke in the ordinary Welsh coke-oven from a mixture of very finely ground anthracite and coking coal. A considerable quantity of a beautiful-looking coke was made, and it was used in one of the blast-furnaces. The coked portion, however, burnt out readily, whilst the anthracite did not, and the furnace became choked up completely with the fine anthracite dust, which had ultimately to be dug out by hand. He did not think the same thing would occur with other materials, nor was he prepared to say that the same unfortunate result would have been obtained in a modern blast-furnace, but he thought it worth while to mention the fact, as he believed that there was no record of the experiment anywhere.

He strongly agreed with most of what Dr. Lessing had said, but he would like to remind the meeting that Great Britain was not in the same position as Germany in dealing with coal. Germany was in the fortunate position that she had practically only one compact coal-field, the Ruhr, and it was much easier to do in one homogeneous field what had to be done in Great Britain in half-a-dozen different fields, which produced different fuels, for entirely different purposes, and for entirely different markets. He could not conceive, for instance, one and the same selling agency suiting Northumberland, with its export trade, and Nottingham, with its internal coal trade.

Mr. E. C. Evans (London) said that blending offered technical possibilities in practically every phase of fuel utilisation. For example, there were a number of cases on record where a blend of two coals, or a blend of coke and coal, had given better results under a boiler than did either of the coals used separately. Several cases had also come to his notice of works, using strongly-caking coal, where difficulties were experienced in gas-producer operation. In those cases it was always worth while investigating the possibility of blending the coal used either with coke breeze or, if it were available, with non-coking coal.

Coal blending for carbonisation purposes opened up a very big field indeed. The difference in structure between a coke made from blended coals and those from the coals themselves was considerable, and

theoretically blending offered most attractive possibilities in some districts. In Derbyshire, for example, where the coals oxidised possibly within twenty-four hours after extraction, the cokes produced were weak, and the difference in consumption of those cokes in the blast-furnace, as compared with a high-class Welsh or Durham coke, might be as much as 4 cwt. or 5 cwt. per ton of pig. If there were any possibility of improving Derbyshire coal, either by blending with a bituminous coal of the type of Kent coal, or by pre-treatment along the lines of the Saar system, and finally blending before carbonising, it would be of great importance to the iron and steel industry. The same thing applied in Scotland, where the supplies of splint coal were dying out, and where the possibilities of coke furnaces had to be faced. The blending of weakly coking coals with others of higher caking index might offer very considerable advantages in Scotland, once the correct blends had been ascertained. Each particular coal had to be treated on its own merits, however, and it meant a vast amount of individual work at the coke-ovens and iron and steel works before any definite system could be laid down. When once the correct blend had been discovered, there then came the technical question of how to attain that blend in practice, and unfortunately few of our existing coke-oven plants were laid out for blending. It meant, probably, separate bunker accommodation—possibly an alteration in the arrangements of the washery plant; it meant a mixing plant; it meant, too frequently, a very heavy capital cost, together with the addition of handling charges, which made the proposition an expensive one; and if on top of that there were heavy rail freights to bring coal from one coalfield to another for the purpose of blending, the items on the debit side of the balance-sheet mounted up very appreciably. Against those there was the advantage, possibly, of a better coke, but it was always very difficult for the coke-maker to find out exactly what that coke was going to be worth in the open market, and whether the price he would get for it would pay for the increased cost which had to be incurred in its preparation. There were still a host of problems to be faced, but, if they could be solved, he believed coal blending would offer very considerable possibilities to the iron and steel industry.

Mr. H. M. Ridge (London) remarked that any improvements which could be effected in carbonisation of coal so as to obtain a suitable metallurgical coke would be of vital importance to the iron and steel industries. If and when low-temperature carbonisation became a practical proposition, it should, owing to the recovery of by-products, assist in reducing the price of the coke as delivered to the blast-furnace plant, and every penny by which the price of coke could be reduced was a direct gain, as it meant a corresponding saving in the cost of making pig-iron and steel. Unfortunately, the very name of low-temperature carbonisation was looked upon with disfavour, because of past financial operations, and this had not done any good on the

technical side. At the same time, excessively optimistic articles had appeared in the lay Press, which had boomed products and processes in an unjustifiable manner. If a number of those interested in the subject could be brought together, under the ægis of the Iron and Steel Institute, to deal with it in somewhat the same interesting manner as Dr. Hatfield's Committee had dealt with the heterogeneity in steel, it would be of advantage to the iron and steel industry, to coal-mining, and to the whole nation.

With regard to coal blending on the Continent, some thirty years ago, when he was a student at Freiberg, blending was carried out in Saxony at certain coke-ovens dealing with coal from several seams of different quality. Those coals were systematically mixed, and he remembered being told in the early 'nineties, at Zaukeroda, about the extra cost which they were incurring at that time for mixing the coals, which in the absence of mechanical means had to be done by hand before the mixture was fed into the coke-ovens, but they knew then that appreciable benefit was derived from mixing the coals.

The author mentioned the name "gasol" in connection with the Fellner and Ziegler process. The production of that material was one of the developments which had been first carried out at Gelsenkirchen a couple of years ago. After the removal of the tars and benzol, the uncondensible gas was compressed and put into steel cylinders, to be used for welding, and to replace acetylene generated from carbide. He understood it brought in quite an appreciable revenue to the carbonisation plant.

In his opinion, the scope of the paper was somewhat limited, and he would like to ask whether the Council of the Institute would not in the near future arrange for a full discussion of the question of low-temperature carbonisation and coke-oven practice.

Mr. A. Hutchinson (Member of Council) said that he desired to emphasise the point stressed by Professor Louis, that what might apply to a country like Germany, and perhaps in a lesser degree to America, might not apply to this country. There was in Great Britain, at any rate in some districts, probably the best coking coal in the world, and one object which should always be kept in view was to improve the quality of the intrinsic coke itself. If it could be further improved by blending, then that would be undoubtedly desirable, but having got really good coking coal, it was important that the very best possible results should be got out of it, and he would suggest that, in considering blending, the importance of thoroughly cleaning the good quality coals should not be lost sight of. If a method of really good dry-cleaning could be devised, it would produce, perhaps, a greater improvement in our blast-furnace cokes than blending alone.

There was no doubt that a low quality coke derived from a coking coal could be very considerably improved by very fine grinding. The three processes of dry-cleaning, blending, and fine grinding might give

a much better result than would be obtained from merely blending alone.* He thought the lesson to be learned was that the industry should keep its eyes open, and continue researches on those other matters. The combination of proper cleaning, proper grinding and blending would, no doubt, ultimately give the industry a really good blast-furnace coke.

Mr. F. W. Harbord (Vice-President) thought all were agreed that, from the technical point of view, blending might in many cases greatly improve Great Britain's cokes, but the question was more an economic one than anything else. In very few cases would it be possible to transport coal in order to get the best mixture for blending, owing to the transport and handling charges.

With reference to the suggested use of low-temperature carbonisation coke for blending, he could not conceive of any case in which it could possibly pay in this country to first subject an appreciable portion of the coal to low-temperature carbonisation, and then to grind that coke up to blend it with coal. He thought he was right in saying that of all the processes mentioned, with possibly two exceptions, not one of them was making money. Those that were paying their way were working under special conditions, treating coals not generally obtainable, which gave an exceptionally high yield of by-products, and they had a local market close at hand for the fuel, &c., produced. Speaking generally, there was no low-temperature process to-day which could treat the different coals of Great Britain and produce low-temperature coke at a profit, and, until there was such a process, he thought it was useless to talk of using low-temperature coke for blending for metallurgical purposes. Assuming that a blended coke, made under the best conditions, were available, how much would be saved in the blast-furnace? Would it pay for the extra cost involved? He thought it was essential to keep the commercial side of low-temperature carbonisation always in view, as many of the statements made as to the commercial possibilities of low-temperature carbonisation were most misleading. A very large amount of experimental work was being done, and there were several very promising processes; he hoped that at no distant date a successful process would be developed. He would like to ask the author if he knew definitely of any low-carbonisation process which was working commercially on such coals as were obtainable in quantity in the different colliery districts, and making a profit.

Mr. T. P. Colclough (Sheffield) remarked that as a user of coke he naturally regarded all questions of blending with suspicion. The author had asked for co-operation. Personally, he thought it was absolutely essential that in any work which was being done in that direction the blast-furnace manager—the coke user—should be fully

acquainted with the whole of the processes which were going on, in order that he might know what would happen in his blast-furnace. He agreed with the remarks made by Professor Louis as to the great danger and the enormous amount of work to which a blast-furnace man was often exposed owing to what he termed the coke-oven manager "monkeying about" with his coals and mixtures. Neither would he like it to go out that we in England were behind the world in the question of blending. Anyone connected with works knew that the blending of coals for different processes had been practised from the days of our grandfathers. In the case of producer coal for ordinary steelworks use, it was quite a common thing to have consignments coming from different collieries. It was known how they behaved in the producers, and the wagons of coal were charged in so as to give the best possible mixture. A better result was got by mixing those coals than could be obtained from any one of them separately.

The blending of coals had one very grave disadvantage so far as the user was concerned. Dr. Lessing had mentioned the great economies which had been obtained in Germany, but they were the result of blending in stuff which would not be looked at by anybody if it were sold separately. It came along hidden away.

A previous speaker had advocated the setting up of a committee to investigate the subject of blending. An extensive research was, however, in progress in the country at the moment, involving the examination of practically every seam. That work should be completed before any large-scale attempts were made at blending. It was absolutely essential to have the scientific data of every seam before the question of blending was gone into. In the Sheffield area there was one colliery which was fortunate enough to have on its staff a man who was doing work for the Fuel Research Board. He had carried out tests on every seam which the colliery company had in their pit, and as a result of the information which they had acquired they were blending their coals and producing a very satisfactory coke, and in that way were making an economic use of seams which before could not be used, and they were tending to improve both the coal industry and the blast-furnace industry.

Mr. Brownlie, dealing first with low-temperature carbonisation, replied that it was difficult in a short space to give any adequate idea of the complexity of the subject, and of the work which had been carried out upon it. Altogether, up to the present time, over 200 separate processes of low-temperature carbonisation had been tried out for coal, brown coal, lignite and shale, on a comparatively large experimental scale. In fact, in the aggregate, the work that had been undertaken was of such a comprehensive character that it was very difficult to generalise, and he was afraid many people who wrote and talked on low-temperature carbonisation had small knowledge of the subject.

Dr. Lessing had pointed out clearly what was going on in Germany with regard to blending. It was obvious, as they well knew, both in Germany and in the United States, that the exact proportions for blending had to be found, and then stuck to rigidly, and it was necessary to mix the materials on proper scientific lines. Simply to throw one truck of coal on top of another was waste of time, but quite a number of people regarded such a proceeding as blending.

With regard to irregularity in the quality of the coal, one of the best examples of the resulting inefficiency was shown in power station operation. The modern steam-driven super-power station represented a remarkable advance in technique, and 90 per cent. continuous efficiency in the generation of steam was within sight. To anybody who had had experience of boiler plant work this was an almost incredible achievement, and to-day in America tests of 94 and 95 per cent. efficiency were being obtained on short tests up to 20 hours. In this connection even a small irregularity in the quality of the coal affected the working, and the use of pulverised fuel offered a solution to this difficulty.

Professor Louis had mentioned the work of Siemens on blending which was most interesting. With regard to the use of anthracite for blending with bituminous coals, this was certainly an intricate question; generally, as described in the paper, anthracite had been used more in connection with oils and tars. He did not agree altogether with Professor Louis when he said that there was one compact field in Germany, whereas there were many fields in Great Britain. He did not see any reason, other things being equal, why this country should not be divided into areas, and those areas regarded as one field equal to the one field of Germany, where the coals also varied to a considerable extent.

With regard to the blending of coal for steam boilers which Mr. Evans had mentioned, an interesting question in that connection was the use of this principle to prevent black smoke. Some coals would smoke badly for no apparent reason so far as revealed by chemical analysis, but such coals could be used without difficulty when blended. In fact, quite a proportion of the smoke of the country from steam boiler plants could be prevented by mixing coals or other fuels. With regard to the oxidation of coals, referred to by Mr. Evans, the cases which he had mentioned in the paper were also those of Derbyshire coal, and it was quite possible that low-temperature carbonisation might be very successful with certain of those coals, as was now the case in the Saar.

Mr. Ridge had mentioned "Gasol" and the Fellner and Ziegler process of low-temperature carbonisation. As he rightly remarked, the "Gasol" apparently possessed remarkable advantages for welding purposes.

With regard to Mr. Hutchinson's remarks, it was quite true that this country had the best coking coal in the world, but even so there

was no need to waste it, and if there could be mixed in that coal 25 per cent. of non-coking coal, it ought to be done.

Mr. Harbord had asked whether any low-temperature carbonisation process had yet proved a commercial success? It was difficult to answer that for these reasons. He did not know exactly what was meant by "commercial success," and there was scarcely any process which in its original stages had paid a dividend.

Blending was not to be looked at as if it were a question of a merchant trying to smuggle into his deliveries a lot of "dud" coal. The day for that sort of thing had gone by, and industries had to consider their mutual advantage.

CORRESPONDENCE.

Mr. JOHN ROBERTS (Harrow) wrote that in a paper on blending it was absolutely necessary to have a correct conception of the nature and properties of the materials to be blended, hence the necessity for clear definitions. The classification and definitions of coals on p. 230 were unsatisfactory. The first definition of coking coal would exclude practically all coking coals used in this country, since it was held that the cementing material must bind the whole mass *without undue swelling*. Did not most coking coals coke with undue swelling, and was not the purpose of blending to reduce that swelling? The most strongly swelling coals in this country were those of Kent and Yorkshire, which must now, according to that definition, be classed as non-coking.

The second class of non-coking coals "contain such an excess of resinous material that it causes the charge to swell unduly, giving porous and soft coke." That was an amazing definition of a type of non-coking coal. Surely the author would have read in Parr's publications which he mentioned that *coking* coals contained an excess of resinous material, and for that reason it was proposed to utilise it as a binder. Thus, on p. 22 of the 1912 Bulletin would be found: "The readiness with which the cementing material ran to waste seemed to indicate that the coal contained a superfluous amount of it—more than was necessary for binding itself together."

Before proceeding further it was advisable to state what was meant by the term "coking coal." A coking coal was one which, when ground to pass through a $\frac{1}{10}$-inch mesh, and subsequently heated rapidly at a temperature of about 900° C., would fuse and yield a coherent residue. A non-coking coal was one which would yield a non-coherent residue under the same conditions. The latter could be further classified into high-oxygen non-coking and low-oxygen non-coking, so as to distinguish between the high-volatile non-coking coals and the anthracitic.

The author stated that Parr and his co-workers proved conclusively that "in order to obtain a coherent coke, the original coal must not only contain just the right amount of resinous material," &c. The American investigators did not prove that the coal should contain *just the right amount*, nor did they prove that the binder was resinous material. The latter assertion had not yet been proved, and the former was incapable of proof, because it was a fallacy. A coal might yield a coherent coke even when it contained twice or three times the right amount of binder.

In the next paragraph he credited Parr with the suggestion to blend with breeze for high-temperature carbonisation, but the idea had been patented in this country several times prior to 1912—for example, by Souquière (1859), Greenfield (1889), and Cochrane (1900).

Mr. Brownlie appeared to regard Parr and Olin as the pioneers in blending coke dust and anthracite at low temperature, but he would find that George Haycraft, of Pontardulais, patented the process worked out later by Parr and Olin (British Patent 18156, 1895). Haycraft stated: "I mix with the anthracite, or other non-bituminous coal, or coke breeze, a suitable quantity of fine bituminous coal; equal quantities of each have been found to give good results." He considered that "for a marketable fuel, it is necessary that the block or briquette should be sufficiently hard and strong to bear handling; that it should be practically uniform throughout, in order to burn evenly, and without becoming disintegrated; and that it should be practically smokeless." The foregoing should be compared with the following sentence from p. 24 of Bulletin 60. "In both cases a strongly cohering mass is produced which meets the requirements of handling, storage, and combustion with the greatest efficiency and the least formation of smoke."

Haycraft produced his fuel "by incipiently coking, in a uniform manner, the bituminous coal which constitutes the cementing or cohesive medium in the fuel." The degree of temperature employed was 700° to 900° F. (370° to 482° C.). It will be observed that the temperature range was practically identical with that employed by Parr and Olin, and he (Mr. Roberts) maintained that their results gave no further information than could be obtained from experiments carried out according to Haycraft's specification. That was not to be taken as indicating that Parr and Olin's results were not interesting and instructive. They certainly were, and, moreover, they anticipated a British chemist in a remarkable way. For example, on p. 24 of the 1912 Bulletin they suggested "a process of fractional coking, or coking in two stages. The first result at the lower temperature furnishes a product which, when ground to a moderate degree of fineness and mixed with a small portion of fresh raw coal, would furnish the essential conditions for producing a coke of dense nature." The foregoing might be compared with Example II. of the application of Illingworth's process (Patent No. 186085, 1921). "The above-mentioned bitu-

minous coal was carbonised at 500° C.; the product evolved 10 per cent. volatile matter at 900° C., 0·75 per cent. at 500° C., and none at lower temperatures. This product was mixed with virgin coal in the following proportions: virgin coal 45 per cent., product 55 per cent. A dense hard fuel resulted when the blend was carbonised at 500° C."

Further, Parr and Olin also anticipated the Fuel Research Board. On p. 40 of the Board's Report for 1924, lines 6 to 10, there appeared the suggestion that Sutcliffe's briquetting process could be improved by preheating the coal before briquetting. Not only was it obvious from Sutcliffe's specification that he had been aware of this in 1915, but the idea was published in Bulletin 60, p. 22, as follows: "The apparent plasticity exhibited by the coal during certain stages of the treatment suggested the idea of compressing it into a briquette at the time when it would most easily yield to pressure, and when it would presumably cohere without requiring an artificial binder."

The Fuel Research Board stated: "Experiments in the laboratory at the Fuel Research Station showed, moreover, that on a small scale strong briquettes could be made without binder at much lower pressures (than 10 tons) if the coal were heated to a temperature just below that at which active decomposition appeared."

The foregoing showed that it was somewhat risky to attempt to state definitely who were the pioneers in blending. It was a delicate question which was best left to the Comptroller of Patents to decide as occasion arose. The Indians used to blend semi-coke dust with coal to make semi-coke, or *poira coila*. It was of no concern how many centuries that practice had been in vogue, but what really mattered was that by so doing they made a better fuel than without blending.

The statement that good quality coking coals did not require blending for high-temperature carbonisation was at variance with the results of researches on the question, and it was unwise to ascribe the coking property to the amount and quality of the volatile matter. In the matter of the practical application of blending, this country might not be keeping pace with other countries, but as regards scientific researches on the question, and real contributions to the solution of carbonising problems, Great Britain deserved better than second place.

The reference to the Dalton Main coal should be taken with some reserve. In Fuel Research Board Technical Paper No. 1, p. 8, that coal was described as "Clifton Colliery, Nottingham; Dalton Main (J)." On p. 9 it was referred to as "Dalton Main (J)." Was that coal sample obtained from the Clifton Colliery, Nottingham, or the Dalton Main Colliery, Yorkshire, or was it a mixture, and, if so, in what proportions? The accuracy of the Board's assay apparatus was tested with that coal (pp. 6 and 7 of the above-mentioned Technical Paper).

Budd's patent was not clear in that he did not state whether his "non-coking coal" was a high-oxygen coal or a low-oxygen anthracitic

coal. In all probability it was the latter, which would be the class of coal obtainable in Ystalyfera.

Illingworth's process, mentioned on p. 241, should be studied in conjunction with the prior publications of Haycraft, and Parr and Olin.

Mr. Brownlie referred to the Ellistown Main coal as non-coking; he was to be excused for that, as the same error frequently occurred in the Reports issued by the Fuel Research Board. The coal in question would fuse and yield coke without special treatment, but, if desired, it could be made to yield a non-coherent residue. The object in testing coking properties, however, was not to see whether the coal could be made to yield a non-coherent residue, but to determine whether it would yield coke. It might also be pointed out that the author referred to that coal as a Yorkshire bituminous coal, whereas it was really a Leicestershire coal.

Mr. Brownlie was not strictly correct when he suggested that in general he (Mr. Roberts) proposed the use of breeze, as he should have been aware that the coke-breeze process had been superseded by one in which the chief, if not the only, inert material was a high-volatile non-coking coal.

The statement that it was largely due to the work of Parr that oxidised coals played an important part in low-temperature carbonisation was to be questioned. Superheated steam was used to expel oxygen and avoid oxidation. Parr did not suggest the oxidation of the coal. Perhaps Mr. Brownlie could quote the author who first proposed the deliberate oxidation of coking coals to prevent expansion in low-temperature processes. The proposal made by Sutcliffe and Evans (p. 258) had been published before their paper appeared.

Percy [1] made the observation before the low-temperature problem arose. In dealing with a strongly coking coal he found that it could be heated at 300° C. "for about a quarter of an hour without sensibly losing its property of swelling up and coking, but when it is exposed to this temperature during one or two hours, it does not swell up when subsequently heated to redness, and yields only a slightly fritted coke." It was only a short step to suggest that the time and temperature should be so controlled as to reduce swelling without destroying the coking properties.

Finally, Mr. Brownlie had devoted six lines to the most important aspect of blending, namely, the prospect of manufacturing semi-coke under high-temperature conditions in coke ovens, rendered possible as a result of blending. Members who were interested might refer to an article on the subject which appeared in *Colliery Engineering*, November 1925.

Mr. Brownlie wrote in reply to the interesting and informative contribution of Mr. John Roberts that he could not quite follow some of the criticisms. For example, it was not stated in the paper that

[1] "Fuel," pp. 308, 309.

Professor Parr first suggested the use of coke breeze for blending, but it was specially pointed out that Souquière was one of the pioneers in 1859. The reference to the early work of Haycraft in this connection was most interesting, and he agreed with Mr. Roberts that it was a matter of extreme difficulty to decide definitely who originated blending for carbonisation. At the same time he saw no reason for departing from the statement in the paper that Parr was the scientific pioneer, while Budd had carried out the work, as far as the use of different coals was concerned, on a large scale in 1850. That Budd most thoroughly understood the principle was indicated by the very lucid wording of his Patents.

Mr. Roberts quite rightly emphasised other sections of the remarkable pioneer work of Professor Parr in low-temperature carbonisation. The idea alluded to by the Fuel Research Board of heating coal before briquetting was more than half a century old, and was therefore carried out long before the time of Parr and Olin. But they seemed to have been the first to study all those phenomena on really systematic lines in the laboratory. He did not say that all good quality coking coals did not require blending; on the contrary he had specially pointed out that much of the coal generally regarded as having good coking qualities could be improved by slight blending, even if only to reduce the wear and tear on the ovens. With regard to the definite use of oxidised coals for blending in low-temperature carbonisation, he did not know who first hit on that idea, but he believed the credit was due to Parr.

Finally, he regretted that he differed from Mr. Roberts with regard to the definitions of "coking" and "non-coking" coal, what constituted "undue" swelling, and the difference between "volatile matter" and "resinous content." After all it must be remembered that, in such a highly complex material as coal, all such terms were intended rather as a convenience of expression than as an exact scientific definition, which applied more or less to all scientific progress.

Iron and Steel Institute.

NOTES ON THE "COMBUSTIBILITY" OF COKE AND DIRECT REDUCTION IN THE BLAST-FURNACE.[1]

By W. W. HOLLINGS.[2]

As far as the author has been able to ascertain, the doctrine of "combustibility" originated in a paper by H. P. Howland, entitled "Calculations with Reference to the Use of Carbon in Modern American Blast-Furnaces," read before the American Institute of Mining and Metallurgical Engineers, and published in their Transactions for the year 1917, p. 339, &c.

In that paper the working results of a large number of American furnaces were passed in review, and, as they appeared to show that no greater proportion of carbon was burnt at the tuyeres in furnaces working on very low consumptions than was burnt in furnaces working on comparatively high consumptions—indeed, rather the reverse—the author (Howland) assumed that the importance usually assigned to indirect reduction in the furnace was misplaced, and that a certain amount of direct reduction was desirable.

"It seems clear, therefore," he said, "that in the low coke furnaces one of the most important, if not the most important, function of the carbon burnt at the tuyeres is to produce heat to enable the carrying on of the direct reduction rather than to produce CO for indirect reduction." And again, "On this basis it becomes very essential that our carbon shall burn instantaneously to CO in order that the resulting heat shall be localised where

[1] Received July 9, 1925.

[2] [Mr. W. W. Hollings, author of the following notes, died on June 17, 1925. For many years he had suffered seriously from bad health, but notwithstanding this disability he devoted himself whenever possible to a study of the theoretical side of blast-furnace practice. He was particularly interested in the discussion arising out of James Gayley's paper in 1904, and a paper read by A. E. MacCoun before the American Iron and Steel Institute in 1915. This latter paper he regarded as the most complete and satisfactory exposition of the heat balance of blast-furnace operation hitherto published. It was his earnest wish to have carried out a similar series of experiments and observations with a view of proving the two points referred to in the last paragraph of these notes.]

needed. . . . We would say, therefore, that the most desirable thing about coke is that quality in the carbon which shall allow of its being instantaneously burnt to CO, and thus result in the maximum concentration of heat where needed."

This idea that a concentration of heat could be obtained in the hearth by means of a special "free-burning" quality in a coke was widely taken up, and a number of investigators once again demonstrated that the solubility of different cokes in a current of CO_2 differed widely at various and corresponding temperatures. Some even suggested that the measure of the solubility of coke in CO_2 should be accepted as an index of its free-burning qualities and of its suitability for work in the blast-furnace. As, generally speaking, the softer a coke the greater its susceptibility to the action of CO_2, the above view would seem to be directly contrary to practical experience, where soft coke is not regarded with much favour.

These experiments, however, were all carried out at temperatures greatly inferior to that ruling before the tuyeres in the blast-furnace, so that they do not seem to serve any useful purpose. On the other hand, researches by the American Bureau of Mines on furnaces in actual work demonstrated the fact that there was no difference in combustibility in commercial cokes before the tuyeres of a blast-furnace—*i.e.* that at a temperature approaching 2000° C. and with the blast heated above the point of combustion of the coke, all cokes were consumed equally within a given space from the tuyeres.

Any conclusions drawn by Howland with regard to the advantages derived from direct reductions are annulled by the statement that, in the calculations on which he based his views, no allowance had been made for the moisture contained in the atmosphere, nor for the nitrogen contained in the coke. Indeed, he specifically stated that he considered them of no importance, "aside from the fact that there may be some nitrogen from the coke and that we have assumed the air to be dry at 62° F., the method (employed in the calculations) is exact. In my (Howland's) opinion, neither of these points is of enough value to counteract the complications introduced by them."

Far from these points not being of enough value to counteract the complications introduced by them, they are just the factors

which control the accuracy of any estimate of the amount of carbon consumed by direct reduction.

This is best made clear by an actual example, and for this purpose Howland's own data may well be used, taking the figures furnished by him and submitting them to examination under two sets of conditions:

1. Dry air at 62° F. and no allowance made for the nitrogen in the coke (the conditions he assumes in his paper).

2. Air at 90° F. containing 7·5 grains moisture per cubic foot—representing extreme summer conditions in the U.S.A.—with a nitrogen content in the coke of 1·0 per cent. of the fixed carbon therein.

Data from Howland's Paper.[1]

Coke consumed per ton pig iron	1673 lbs., containing	88·6	per cent. carbon
Limestone charged ,, ,,	780 ,, ,,	12·0	,, ,,
Flue dust made ,, ,,	94 ,, ,,	9·5	,, ,,

1673 lbs. coke at 0·88 carbon contain . . .		1482·3 lbs. carbon
Loss in flue dust (94 × 0·095) . .	8·9 lbs.	
Absorbed in pig iron (2240 × 0·04) .	89·6 ,,	
		98·5 ,, ,,
Total carbon from coke in gases. . . .		1383·8 ,, ,,
Carbon from limestone (780 × 0·12) . . .		93·6 ,, ,,
Total carbon in gases		1477·4 ,, ,,

Proportion of total carbon in gases due to carbon from coke:

$$1383 \cdot 8/1477 \cdot 4 = 0 \cdot 9366.$$

Gas Analysis.	Per Cent. by Volume.	Per Cent. by Weight.	
CO_2	15·1	22·289	C 15·582
CO	23·6	22·173	O_2 28·880
H_2	2·7	0·182	
N_2	58·6	55·356	

Proportion by weight per cent. of carbon from coke in furnace gases:

$$15 \cdot 582 \times 0 \cdot 9366 = 14 \cdot 595.$$

The carbon contained in the gases from a blast-furnace is derived from three sources:

(*a*) Carbon oxidised by atmospheric oxygen at the tuyeres.
(*b*) Carbon oxidised by oxygen derived from the burden.
(*c*) Carbon derived from the CO_2 given off by the carbonates of the burden.

[1] Vide *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1917, pp. 354–355.

Nitrogen may be considered as being derived from two sources only—the blast and the coke.

If the proportion of the total carbon in the gases which is furnished by the carbonates of the burden be ascertained, it is possible to state an equation from any given blast-furnace gas analysis which shall give the proportion of carbon burnt at the tuyeres, or, conversely, that employed in the direct reduction.

Let:

a be the proportion of carbon burnt by the O_2 of the blast;
b ,, ,, of carbon burnt by the O_2 of the burden;
c ,, ,, of carbon contained in the carbonates;
x ,, ,, per cent. by weight of carbon in the gases;
y ,, ,, per cent. by weight of nitrogen in the gases;
m ,, ,, per cent. by weight of nitrogen in the coke;
n ,, ratio N_2/C in the gases formed at the tuyeres.

Then:

$$a + b = x - c \quad . \quad . \quad . \quad (1)$$
$$na + m(a + b) = y \quad . \quad . \quad . \quad (2)$$

Case 1.

Dry air at 62° F. with no allowance for the nitrogen contained in the coke.

To burn a unit of carbon to CO at tuyeres requires 1·333333 units O_2.
N_2 equivalent of above $(1{\cdot}333333 \times 76{\cdot}9/23{\cdot}1) = 4{\cdot}438663$.

Substituting values from the gas analysis and the above value for m in the equation given, we have:

$$a + b = 14{\cdot}595 \quad . \quad . \quad . \quad (1)$$
$$4{\cdot}438663\,a = 55{\cdot}356 \quad . \quad . \quad . \quad (2)$$

whence $b = 2{\cdot}123$

Total carbon from coke in furnace gases	1383·8 lbs.
Carbon consumed by direct reduction (1383·8 × 2·123/14·595) .	201·5 ,,
Carbon burnt at tuyeres	1182·3 ,,

Case 2.

Air at 90° F. containing 7·5 grains of moisture per cubic foot, and a nitrogen content in the coke amounting to 1·0 per cent. of its fixed carbon.

Air at 90° F. containing 7·5 grains of moisture per cubic foot has 5·4967 per cent. of its available O_2 at tuyeres supplied by the moisture.

To burn a unit of carbon to CO at tuyeres requires .	1·333333 units O_2
0·054967 of above derived from the moisture .	0·073301 ,, ,,
Leaving for dry air	1·260032 ,, ,,
0·0269/23·181 of above derived from CO_2 in air .	0·001462 ,, ,,
Leaving for CO_2 free dry air	1·258570 ,, ,,
N_2 equivalent of above × 76·743/23·181 . .	4·166621
Carbon derived from CO_2 of atmosphere :	
0·0202/23·181 × 1·260032	0·001096
Carbon from cokes	1·000000
Total carbon in tuyere gases per unit carbon from coke	1·001096

Ratio N_2/C in tuyere gases per unit carbon in coke :
4·166621/1·001096 = 4·161644.

Substituting values in equation :

$$4{\cdot}171644\, a + 0{\cdot}01\, b = 55{\cdot}356 \quad (2)$$
$$0{\cdot}010000\, a + 0{\cdot}01\, b = 0{\cdot}146 \quad (1)$$

whence $a = 13{\cdot}266.$

Total carbon from coke in furnace gases	1383·8 lbs.
Carbon burnt at tuyeres (1383·8 × 13·266/14·595) . .	1257·8 ,,
Carbon consumed in direct reduction . . .	126·0 ,,

Were a sample of gas, therefore, to be collected from a blast-furnace working under extreme summer conditions, and the amount of direct reduction taking place in the furnace estimated therefrom on a basis of dry air at 62° F. and with no allowance for the nitrogen in the coke, there would be an error of practically 60 per cent. in the result obtained.

Howland also assumes that only the carbon burnt at the tuyeres is capable of taking part in the indirect reduction of the ore. This is not so. The reduction of the silicon, phosphorus, and manganese, and the fixation of the sulphur in the slag, according to the reaction :

$$FeS + CaO + C = Fe + CaS + CO,$$

all take place at temperatures superior to 1000° C., so that any carbon oxidised under these circumstances can only be in the form of the lower oxide (CO_2 cannot exist in appreciable quantities in the presence of carbon at temperatures above 1000° C.).

As the decomposition of the limestone only takes place to any considerable extent at temperatures above 800° C. (the American

Bureau of Mines gives the dissociation temperature of limestone as 892° C.), it follows that there must be a certain proportion of carbon burnt to CO by this means also—the product of the solution of carbon by the CO_2 at the above temperature.

At the temperature of decomposition of $CaCO_3$ and under the conditions prevailing only about 2·0 per cent. of carbon can exist as CO_2 to 98 per cent. existing as CO. This means that if the carbon introduced by the limestone amounts to 10 per cent. of the total carbon in the gases, then about 80 per cent. of it will be reduced to the state of CO, taking with it an equivalent amount from the coke. So far, then, from it being true that only the carbon burnt at the tuyeres is capable of performing indirect reduction, it is seen from the above that 98 per cent. of the total carbon found in the gases from all sources may assist in this process.

The author has long been of the opinion that the carbon primarily oxidised by the oxygen of the burden is confined, in a correctly designed furnace run under satisfactory conditions, to that required to reduce the silicon, phosphorus, and manganese in the pig iron—that involved in the fixation of the sulphur in the slag and the amount called for to establish the carbon, iron, oxygen equilibrium at the mean temperature of the zone of decomposition of the limestone.

So far as the iron itself (Fe) is concerned, Gruner's ideal—that the whole of the reduction should take place indirectly by means of CO gas—should be fulfilled in practice.

If the above view be correct, then it follows that the amount of carbon burnt above the tuyeres for any given burden and grade of pig iron is a fixed amount per ton of pig iron made. The lower the consumption of fuel per ton of pig iron, the higher will be the proportion of carbon involved in the so-called direct reduction.

Support is given to the above theory in the discussion on Howland's paper, where it transpired that there was a remarkable constancy exhibited in the amount of carbon supposedly occupied in direct reduction, independent of what the total consumption might be.

The researches of the Bureau of Mines on their experimental blast-furnace at Minneapolis showed that it was possible to run a blast-furnace without any direct reduction taking place whatsoever.

In fact, in the experiments referred to, not only was the whole of the silicon, phosphorus, and manganese reduced by indirect means—in this case obviously by means of carbon deposited in the upper reaches of the furnace by the reaction :

$$2CO = CO_2 + C,$$

reaching a point in the furnace where the above reactions became possible, but about 4 per cent. of the carbon burnt at the tuyeres redescended in the form of deposited carbon to be again burnt by the oxygen of the atmosphere.

Direct reduction must involve a greater demand for heat from the furnace, and so should be avoided as far as possible. The author thinks that if a series of trials were carried out on a hæmatite furnace, where the amount of carbon entering the furnace in the form of carbonates could be accurately estimated and correct allowances made for moisture in the blast and nitrogen in the coke, it would be found that much of the supposed direct reduction was non-existent. Any hypothesis that free-burning coke so concentrates the heat in the hearth that an extra amount of direct reduction can take place, or is even desirable, would then fall through.

If, however, another characteristic of free-burning coke is considered, namely, its porosity, there would seem to be grounds for admitting its superiority over dense non-porous coke—always provided that it stood up to its work in the furnace.

There must always be a considerable difference between the mean temperature of the various individual pieces of burden and coke and that of the gases immediately surrounding them during their descent in the furnace. This being so, a coke exposing a relatively greater surface per unit of weight to these gases will arrive at the tuyere level at a temperature more nearly approaching that of the combustion temperature than would a less porous coke, and the higher will be the temperature attained by its combustion in consequence. Similarly, the materials composing the burden when broken down before charging offer an increased surface area per unit weight, and so promote the same efficient preheating on which the temperature of the hearth so much depends. The remarkable figures furnished by some furnaces running on fine Mesabi ores, once the initial difficulty of treating

these fine ores had been overcome, are to be attributed largely to the great heating surface these fine ores expose relatively to their weight.

The marked superiority of charcoal as fuel in comparison to coke may also be largely accounted for by the fact that weight for weight charcoal offers an incomparably greater heating surface to the surrounding gases than does coke. Weight is lent to this view by the fact that the observed temperatures of metal and slag in a charcoal furnace are as high as or higher than that of a coke furnace blown with blast at a temperature many degrees higher.

Finally, the series of reactions for indirect reduction which are usually grouped under—

$$Fe_2O_3 + 3CO = 2Fe + 3CO_2$$

is so slightly exothermic that the excess heat which could be conveyed to the surrounding gases as a result of this reaction is insufficient to counterbalance the normal radiation loss. That is to say, however large or small a proportion of CO we may burn to CO_2 there is no actual increase to the sensible heat of the gases themselves.

The sole source of heat to furnish the sensible heat of the gases is therefore that supplied by carbon burning to CO at the tuyeres.

It is not, then, the proportion of carbon which can, or cannot, be burnt to CO_2 by means of the oxygen of the burden which controls the fuel consumption of the furnace, but the amount of carbon which *must* be burnt to CO at the tuyeres to supply all the heat demands other than that of the mere reduction of the iron.

For a 36 to 37 per cent. burden the limit approached from this angle lies round about 21 cwts. under present practice. This is in close agreement with Sir Lowthian Bell's 20·5 cwts. coke for 40 per cent. burden running on No. 3 Cleveland.

This observation led Sir Lowthian Bell to the belief that the limiting factor was the proportion $\frac{CO_2}{CO}$ in the gases, and that when the figure $1CO_2$ to $2CO$ was reached the gas was saturated with CO_2 at the temperatures prevailing at the outlet and ceased to react with the ore. This proportion is, however, constantly

exceeded in furnaces in the States, and the true explanation of Sir Lowthian's limit is, of course, that to supply the heat demands for the furnace in question, working on the grade of iron mentioned, so much carbon had to be burnt to CO at the tuyeres that the O_2 subsequently extracted from the burden only sufficed to produce the proportion $CO_2 : CO = 1 : 2$, on which he based his limiting factor.

The only lines on which it would seem possible to make any considerable saving on the side of the heat demands of a modern blast-furnace would appear to be :

(1) A very considerable enrichment of the blast with oxygen.

(2) The substitution, so far as may be practicable, of pulverised quicklime blown in at the tuyeres for limestone added at the top of the furnace.

(1) Would result in increasing the rapidity of the cooling curve of the ascending gases, resulting in a lower top temperature for a very considerably diminished volume of gas per unit of carbon burnt.

(2) Would mean the saving of :

- (*a*) The carbon now lost by solution with the CO_2 of the limestone in the reaction $CO_2 + C = 2CO$.
- (*b*) The very considerable amount of heat required to balance the above strongly endothermic reaction.
- (*c*) The heat required to decompose the $CaCO_3$ into CaO and CO_2.

All the heat required for (*b*) and (*c*) has now to be furnished by carbon burning to CO at the tuyeres, which carbon would be saved in addition to that lost by solution in the shaft of the furnace (*a*).

CORRESPONDENCE.

Mr. E. Adamson (Sheffield) wrote that of late years there had been a considerable amount of literature, both in Europe and America, giving details of the reactions taking place in the blast-furnace, but at the best those reactions could only be assumed, for there was no proof possible.

For a long time, right from the days of Sir Isaac Lowthian Bell's experiments, it had been understood that the reduction of ores in the blast-furnace occurred both directly and indirectly, and considerable actual proof would be required for the acceptance of the author's opinion that much of the supposed direct reduction was non-existent.

In the first place, there was direct reduction of ore in electric furnace smelting, which could be done with about 20 per cent. of the fuel necessary in a blast-furnace making hæmatite pig iron. There was surely also considerable direct reduction in the small charcoal furnaces, whose fuel consumption was about 50 to 60 per cent. of that required in a modern furnace making hæmatite pig and using coke as fuel.

It would be supposed that numerous possible exo- and endo-thermic reactions taking place in the blast-furnace gave a logical reason for the high coke consumption in modern blast-furnace practice as compared with charcoal or electric furnace reductions. In modern blast-furnace practice, particularly with minerals graded to size, there was considerable space for gas circulation and the continued transformation $CO \rightleftharpoons CO_2$.

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Iron and Steel Institute.

THE HARDNESS OF CARBON STEELS AT HIGH TEMPERATURES.*

By IAN G. SLATER, B.Sc. (Hons.), and T. HENRY TURNER, M.Sc.
(Respectively Research Student and Lecturer, University of Birmingham).

Introduction.

A recent inquiry, from a well-known firm, regarding the relative hardness of certain rivets at the temperatures employed in practical shipbuilding, resulted in the authors carrying out impact hardness determinations upon three typical samples having different chemical compositions. It had been suggested that rivets made from modern steels of higher tensile values would be harder to drive than the usual mild steel types. The impact hardness values which the authors obtained upon the samples received were found to show considerable variations at temperatures between 700° and 1000° C. This temperature range probably includes that employed in practice during the major part of the operation.

In view of this difference, which indicated that much greater energy would be required to rivet with one steel than with another, the authors decided to obtain further information upon the subject by a survey of technical literature, and if necessary by further experimental work.

Those engaged in manipulating steels in forges and drop forges have been aware of differences in the workability of various classes of steels at elevated temperatures. It is well known that, under identical conditions, the higher carbon steels are harder to forge, and that the dies used in their forging have a shorter life than have those used for mild steels.

Of the properties of steel at high temperatures much is known, tensile, crushing, impact, and other tests having been carried out by different investigators.† The authors were not able, however,

* Received February 16, 1926.

† An excellent and exhaustive bibliography of the effect of temperature on metals is to be found in *Proceedings of the American Society for Testing Materials*, 1924, vol. xxiv. pp. 128–140.

to find any data which they felt answered fully the question in point.

Static tensile and crushing tests are obviously of uncertain value as indications of the amount of energy required to drive a rivet of any particular steel. Work upon low and medium carbon steels has been carried out by dropping a heavy hammer on to heated steel cylinders. The malleability-temperature relationship thus obtained is not necessarily exactly that required, because the deformation of a rivet is frequently more local in character and is produced by several blows. The large deformation due to a single blow of the drop-hammer approximates to the conditions in a forge rather than to those encountered in riveting. Furthermore, it was desirable that the results of tests at high temperatures should be comparable with hardness values obtained at atmospheric temperatures. It was therefore decided, for the work here reported, to use the simple and now well-known impact ball hardness method of test.

Experimental.

A guillotine type of impact hardness testing apparatus was employed. The long rectangular electric furnace, constructed by Mr. E. W. Fell for strain detection experiments, was kindly loaned for the purpose of heating the specimens. The drop-hammer weighed 1½ lbs. and was caused to fall 8·4 inches, giving an impact of 12·6 inch-pounds. With a 10-millimetre ball this energy produced at all temperatures indentations of suitable dimensions, compared with the size of the test-pieces. The furnace, being base metal wound, was only used for the tests up to 950° C., and a similar but smaller tube furnace wound with platinum tape was employed for the higher temperatures. A thermocouple was introduced at the back of the furnace so that the hot junction touched the specimen. Up to 950° C. the couple was nickel-brightray, and for the higher temperatures platinum-platinum-rhodium. The couples were repeatedly carefully calibrated.

The specimens used were cut from ½-inch round bars; each specimen was ½ inch high, the cut surfaces being ground flat on an emery-wheel. They were normalised by heating to 900° C.

for ten minutes and then allowing them to cool in air. The anvil on which the specimens were tested was placed immediately in front of the furnace door, and was provided with a centring device consisting of a V-shaped stop. The latter, being raised only $\frac{1}{8}$ inch above the surface of the anvil, allowed the tongs used for removing the specimen to pass easily over its surface.

The procedure of testing was as follows:

The furnace was raised to the desired temperature, and the specimen was introduced by means of long tongs, which remained in the furnace until the specimen had attained the desired temperature and had properly soaked. The door of the furnace was then opened, and the operator, using both hands, withdrew the specimen, by means of the equally heated tongs, with one straight motion on to the anvil. Simultaneously the hammer was released by means of a foot control.

It should be noted that the operation of withdrawing the specimen and testing could be completed in approximately $\frac{1}{2}$ second, and during the greater part of its travel the specimen was in the heated atmosphere of the furnace. Thus the temperature of actual test can scarcely have varied from that indicated by the thermocouple.

After impacting, the specimens were allowed to cool in air, lightly rubbed on fine emery to remove the surface layer of oxide, and the indentation carefully measured by means of a travelling microscope. The diameter of each impression was measured in two directions at right angles, the mean of the two readings being taken. The measurements did not vary appreciably according to the direction in which they were made, and were read with a maximum error of $\pm$ 0·0025 centimetre. The results of duplicate tests showed very fair agreement, and the figures from which the graphs are plotted are, in all cases, the mean of two or more separate determinations.

The bars tested were analysed and showed the compositions as given in the table, p. 298.

Microscopical examination of the bars indicated no unusual features. In Fig. 1 is shown the relation between the diameter of indentation and the temperature. It was desired, however, to interpret these diameters in terms of Brinell hardness numbers.

Number.	Carbon per Cent.	Manganese per Cent.	Sulphur per Cent.	Phosphorus per Cent.	Silicon per Cent.
1*	0·020	0·088	0·006	0·024	0·070
2	0·047	0·35	0·068	0·08	0·023
3	0·21	0·65	0·045	0·04	...
4	0·61	0·84	0·04	0·04	...
5	0·90	0·51	0·04	0·04	...
6	1·105	0·61	0·04	0·04	...

* Sample of wrought iron of unusual purity.

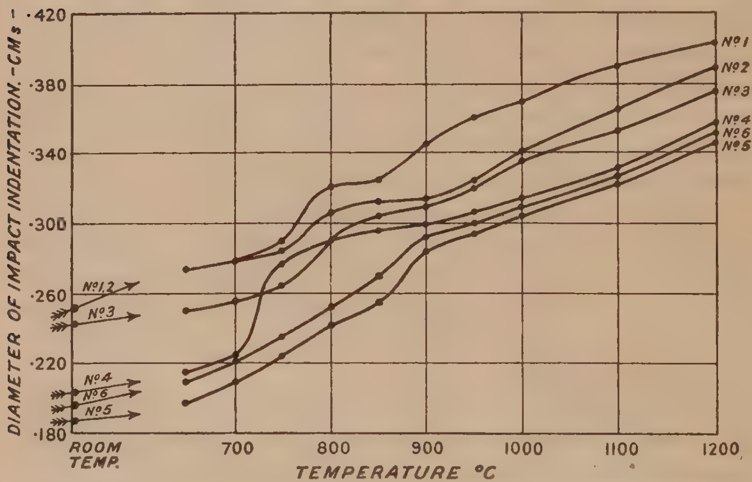

FIG. 1.—Relation between the Diameter of Impact Indentation and the Temperature of the Steels Tested.

The translation curve, Fig. 2, was therefore calculated from Professor Edwards' (1) well-known formulæ:

$$d = CE^{0\cdot25}$$

$$H = \frac{7455}{D^3}$$

where d = diameter of impact indentation produced by a 10-millimetre ball;
E = energy of impact;
C = a constant;
H = Brinell hardness number;
D = diameter of impact indentation produced by a 10-millimetre ball when E = 63 inch-pounds.

Fig. 3 shows the relationship thus obtained between Brinell hardness numbers and temperature for the steels tested.

With the exception of impacts made at room temperature, tests were not made below 650° C., as this lower range had

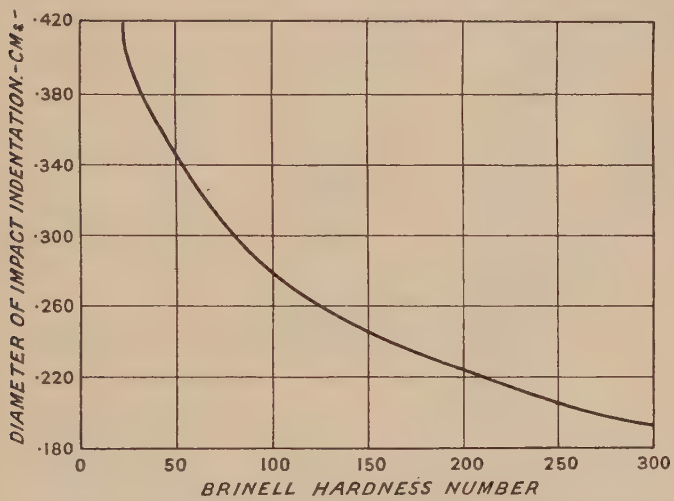

Fig. 2.—Conversion Curve; Impact Indentation Diameters into Brinell Hardness Numbers.

already been fully explored by other workers (2) in the Civil Engineering Department of Birmingham University and elsewhere.

Discussion of Results.

In view of the results obtained, the authors feel justified in recommending the method of test employed as being extremely simple and reliable. Although it has been shown by Edwards that the relationships between the impact indentation diameters and the Brinell hardness numbers hold very closely at room temperatures, direct evidence is lacking of this being the case at higher temperatures. The nature of the curves shown in Fig. 3 does seem to indicate, however, that this method of interpretation is of value. As the contraction of the indentation is greater the higher the temperature, any error in hardness values given will be larger there. Calculation shows, however, that the magnitude of any inaccuracy on this score is absolutely negligible.

The curves in Fig. 3 indicate that a steel loses relatively little of its impact hardness until 650° C., although it has been

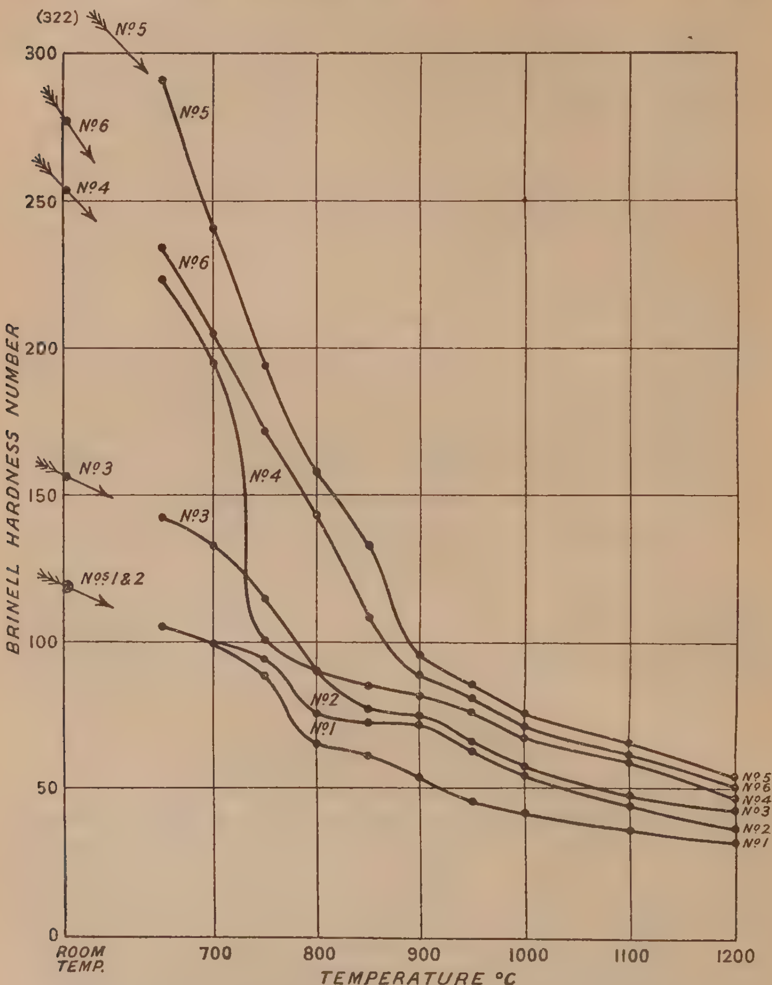

Fig. 3.—Brinell Hardness Numbers of the Steels Tested, as calculated from the experimental data of Fig. 1 by conversion according to Fig. 2.

shown by other workers [2] that under static loads steel exhibits the phenomenon of "creep" very strongly at temperatures considerably below this. Between 650° and 900° C. all the steels

tested soften considerably, the rate of softening depending upon the carbon content. Above 900° C. the decrease in hardness is relatively less rapid, and the hardness values of different steels become more nearly equal. An attempt to convert these impact

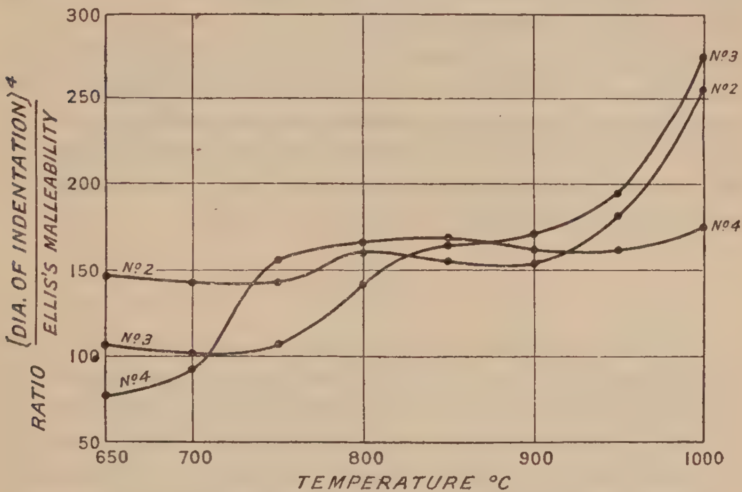

FIG. 4.—Correlation of Impact Indentation Tests with O. W. Ellis's Malleability-Temperature Relationship.

hardness values into maximum tensile stress figures proved that the conversion factor worked well for room temperatures. The values calculated for maximum tensile stress by the same means, from the impact hardness figures obtained at the higher temperatures, were considerably greater than those obtained by workers using the tensile test. This is probably due to the "creep" effect present in all high-temperature static tensile tests.

In order to determine whether the authors' calculated Brinell hardness figures bore any relation to values obtained by other methods of high-temperature testing, the volumes of metal displaced by the ball in the above tests were calculated. It may be shown that $V = kd^4$ very nearly, where V = volume of the indentation, k is a constant involving the radius of the ball, and d = the maximum diameter of the indentation. In Fig. 4 the ratio of these calculated volumes and the volumes of metal displaced in tests [3] with a flat-faced drop-hammer, on cylinders of

steels similar in composition to those used by the authors, is plotted against temperature. It will be seen that in each case the ratio increases with increase in temperature. At the higher temperatures therefore, with given intensities of impact, a relatively greater volume of metal is displaced by a ball-nosed tool than by a flat-faced hammer.

Although the curves shown in Fig. 3 were produced to answer a practical problem and are not complete enough for the metallographist, they do show the deflections corresponding to the Ac points. The apparent anomaly exhibited by the 0·61 per cent. carbon steel in Fig. 3 between 700° and 800° C. has caused the authors to check this curve especially carefully.

Conclusion.

From the above, the authors conclude that, if riveting takes place between 800° and 1200° C., the higher the carbon content, up to the eutectoid composition, the harder to drive will the steels be. The curves indicate also that, if the danger of burning can be avoided, there is a distinct advantage to be gained by using the higher temperatures—at least so far as the energy required in shaping the rivet is concerned. For example, a medium carbon steel rivet will be as soft at 1100° C. as a wrought iron rivet is at 900° C.

It is important, so far as the practical value of these results is concerned, to note that work, such as cutting off fins, done below 800° C. will in all cases require an expenditure of much more energy than would the same operation carried out with the metal above this temperature. This difference is very marked in the steels of higher carbon content.

In the process of riveting by hammering a cooling rivet it is thus clear that, with hammer blows of equal force, the first impact will produce more of the desired shaping than will any one of the subsequent blows, and the number of rivets driven per hour will depend more upon the speed with which the first blow is struck than upon the total physical energy expended.

The above experiments were carried out in the Metallurgical Department of the University of Birmingham under the super-

vision of Professor T. Turner, to whom the authors are indebted for assistance and advice.

REFERENCES.

(1) C. A. Edwards and F. W. Willis, *Proceedings of the Institution of Mechanical Engineers*, 1918, vol. i. pp. 335–369.
(2) F. C. Lea, *Proceedings of the Institution of Mechanical Engineers*, 1924, vol. ii. pp. 1053–1096.
(3) O. W. Ellis, *Iron and Steel Institute: Carnegie Scholarship Memoirs*, 1924, vol. xiii. pp. 47–81.

DISCUSSION.

Mr. Hugh O'Neill (Manchester) felt that the members would agree with the very general conclusions which the authors had drawn. There was very little doubt that the dynamic method of testing for studying a phenomenon such as that described was by far the best. He could only have wished that indentation could have been arranged to take place with the specimens in the furnace, though he did not doubt that very little time elapsed in withdrawing them.

He desired to raise a point of theoretical interest with regard to the use of a ball indenter. A ball was very serviceable and perhaps the best instrument for such work, but it was impossible to be sure that when using one fixed impact energy the results obtained from that one value necessarily told the whole story. The relation between the impact energy and the volume of the indentation produced appeared to be of the form $E = aV^w$. The work of Edwards, Schneider, and others, made that clear. In the expression, a varied with the metal and was a function of the hardness; the index w was also a property of the metal, and gave an indication of its flow behaviour. If the impact hardness were taken as the energy producing unit volume of deformation it could be written—

$$H = \frac{E}{V} = E \bigg/ \left(\frac{E}{a}\right)^{\frac{1}{w}}$$

The hardness then varied with different degrees of deformation, and it depended upon two constants, a and w.

If the dynamic hardness were plotted against the energy, using increasing energies of impact, then the curve for a given temperature, t_1, would be of some form similar to that shown in Fig. A. Unless w were independent of temperature the curve for a higher temperature t_2 would not necessarily fall inside the previous curve, but might cross it. Anomalous results could thus be obtained depending upon the striking energy chosen. For instance, if the energy of impact were E_1, then the metal appeared to be harder at the higher temperature than at the lower temperature; whereas if a higher value of indenting energy E_2 were used the hotter metal appeared to be softer. That effect might occur unless w remained constant with temperature. He (Mr. O'Neill) knew of no direct evidence yet available as to the behaviour of that index with temperature. The information could be obtained on the authors' apparatus by using different striking energies at a constant temperature and finding the values for the relation previously given. The operation would then be repeated for some other temperature and the values of w compared. He (Mr. O'Neill) suggested, however, that

w was constant and that the curves did not cross, because experiments had been made by Kokado showing that *w* was related in a simple way to the index *n* in the Meyer relationship for static ball testing. If that were so, and *w* behaved in the same way as *n*, then the work of Kürth could be applied. He had tested the behaviour of *n* with temperature and found that it remained constant. That chain of evidence

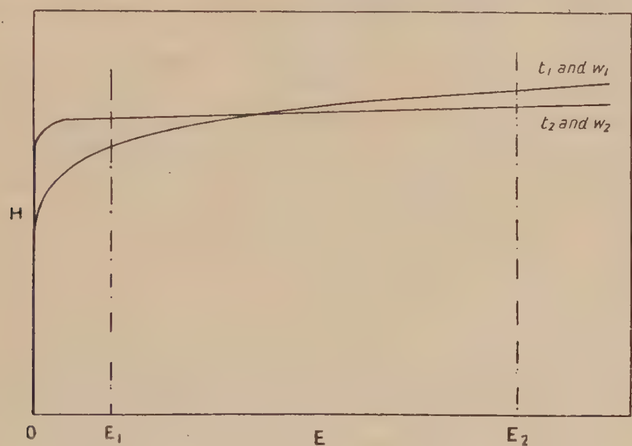

Fig. A.

suggested that *w* did not vary with the temperature of the metal, and then the dynamic hardness curves would not cross. The authors' results obtained at an arbitrarily selected impact energy would, therefore, appear to give a correct impression of the behaviour of the metal to hammer-blows of any intensity.

Mr. T. Henry Turner, in reply, said he was very pleased to have heard Mr. O'Neill's contribution because he (O'Neill) had recently studied hardness testing, and the facts that he had brought forward required serious consideration; the authors would be delighted to talk the matter over with him. They did use the equation mentioned, in a slightly different form, in the paper, and referred to the fact that it was not yet proved that *w* was constant. A point that had not been discussed, but in which the authors were greatly interested, was the last curve shown in Fig. 4. The fact that a round-nosed tool was apparently more capable of deforming metal at a higher temperature than at a lower one relative to the amount of deformation produced by a flat-nosed tool at similar temperatures was of great interest. In any impact the energy went into rebound, surface deformation, and strain in the metal. It was probable that the amount of strain

produced, that is, the sub-surface deformation, would vary in the specimen tested according to the temperature, but the authors knew that it varied also for different materials. They thought it would turn out in the long run that the difference noted was somewhat more fundamental, and that probably it was related to the difference which could be noted in the testing by impact of soft and hard materials with a round-nosed and a flat-nosed tool.

The authors thanked Mr O'Neill for his distinctly useful contribution.

1926, No. I.; Vol. CXIII. Annual Meeting, June 3–4.

Iron and Steel Institute.

THE HARDENING AND TEMPERING OF HIGH-SPEED STEEL.[1]

By A. R. PAGE (Birmingham).

Introduction.

High-speed steels are well known to be very complex alloys, a fact readily grasped when it is considered that even simple types contain elements such as tungsten, chromium, and vanadium, in addition to those usually found in plain steels, while the newer varieties also contain cobalt, molybdenum, &c. Owing to this complexity only one type of steel has been dealt with, the two steels experimented upon being similar in every respect except for carbon percentage.

One steel, denoted by the symbol J1, is that which, in Great Britain, is probably the most popular, and has already received a considerable amount of attention from scientific investigators. It has the following approximate composition :

	Per Cent.
Carbon	0·55–0·65
Silicon	0·20
Tungsten	13·0–14·0
Chromium	3·0–4·0
Manganese	0·4–0·5
Vanadium	0·25–0·50
Sulphur	0·05
Phosphorus	0·06

The other steel on which some tests have been carried out, designated J2, is exactly similar to J1, except that the carbon content is 0·70 to 0·80 per cent.

Very different views on the exact technique of heat treatment are held. Some consider that the proper hardening temperature lies anywhere between 1100° C. and 1200° C., while others assert that the steel must be subjected to a temperature little short of fusion—*i.e.* 1300° to 1350° C. This diversity of opinion can well be understood. The different duties which tools, such as reamers, twist drills, lathe tools, and milling cutters, have to perform are so varied that it seems fairly obvious that one common treatment may not confer the most efficient properties on all these types of tools. In the hardening operation the high temperatures employed

[1] Received September 1, 1925.

cause the molecular mobility of the alloy to be greatly increased, so that the time of soaking is a considerably more potent factor in producing satisfactory results than in the case of straight carbon steels, where the times of soaking are very much longer, bulk for bulk.

The phenomenon of secondary hardening, and the drop in hardness after tempering in the neighbourhood of 400° to 500° C. followed by a subsequent rise in hardness at 600° C., is fascinating, and it affords, in the author's opinion, great possibilities in commercial practice. This phenomenon was clearly shown by Edwards,[1] but his paper dealt in a general and preliminary way with the subject as applied to steels containing tungsten and chromium. No single type was dealt with in close detail, whereas the object of the present paper is to place on record certain observations on one particular type.

This paper consists of two more or less distinct parts, as follows:

Part I.—Preliminary Investigations on the Effect of Hardening and Tempering on the Microstructure, &c., of J1 and J2 Steels.

Part II.—The Effect of Time and Temperature of Hardening and Tempering on the Hardness of J1 and J2 Steels.

Part I. may be considered as being complete, but Part II. is by no means so, and only contains the work accomplished up to date—namely, the full investigation of the hardness of two series in what the author considers to be the correctly hardened state. Further work has been carried out and, though at the moment it is incomplete, it promises to give some very interesting results, which it is hoped to present at a future date.

PART I.

Preliminary Investigations on the Effect of Hardening and Tempering on the Microstructure, &c., of J1 and J2 Steels.

Section I.a.—*J1 Steel.*

The material used in this series of tests was supplied in the form of ½ inch square bar, which had been annealed after rolling. The test-pieces all consisted of small lengths 1½ inch long, so that

[1] C. A. Edwards and H. Kikkawa, "The Effect of Chromium and Tungsten upon the Hardening and Tempering of High-Speed Tool Steel," *Journal of the Iron and Steel Institute*, 1915, No. II. p. 6.

the mass of each was practically the same. Each piece was nicked in two places, in order that it could be fractured after hardening.

The composition of the material was found to be as follows:

	Per Cent.
Carbon	0·64
Silicon	0·12
Tungsten	13·82
Chromium	3·23
Manganese	0·50
Vanadium	0·36
Sulphur	0·04
Phosphorus	0·05

After hardening, each piece was broken into three pieces, to permit of the examination of the fracture and also to provide two further test-pieces for tempering at 600° C. and 680° C., these two tempering temperatures being largely used in the manufacture of high-speed steel tools.

Great attention was paid to the hardening of the test-pieces as regards temperature and time of soaking. Heating was conducted in a small dry-gas-fired furnace, the temperature of which was measured by a Féry instrument, which was repeatedly calibrated against a standard platinum-platinum-rhodium couple. Various temperatures and times of soaking were used, and in all cases the pieces after heating were cooled in a medium air-blast.

TABLE I.

Mark.	Temperature. ° C.	Complete Time of Soaking. Minutes.
A1	1200	1
A2	,,	2
A5	,,	5
A10	,,	10
B1	1250	1
B2	,,	2
B5	,,	5
B10	,,	10
C1	1300	1
C2	,,	2
C5	,,	5
C10	,,	10
D1	1350	1
D2	,,	2
D5	,,	5
D10	,,	10

Tempering was carried out in a salt-bath, the temperature of which was controlled by means of a platinum-platinum-rhodium couple.

The various treatments applied are shown in Table I. (p. 309).

Observations.—Brinell hardnesses, observations on fracture in the hardened state, and the results of microscopic examination are given in Table II.

TABLE II.

Mark.	State.[1]	Brinell Hardness.	Description of Fracture.	Description of Microstructure.
A1	(*a*)	258	...	Normal annealed structure
	(*b*)	426	Raw	Improperly hardened. See Fig. 1 (Plate XXXV.)
	(*c*)	409	...	
	(*d*)	322	...	
A2	(*a*)	258	...	...
	(*b*)	592	Semi-raw	Improperly hardened. See Fig. 1
	(*c*)	534	...	
	(*d*)	426	...	
A5	(*a*)	258	...	...
	(*b*)	694	Finer	Not completely hardened. See Fig. 1
	(*c*)	622	...	
	(*d*)	534	...	
A10	(*a*)	258	...	...
	(*b*)	661	Finer than A5 (*b*). Slightly conchoidal	Not completely hardened. See Fig. 1
	(*c*)	592	...	
	(*d*)	534	...	
B1	(*a*)	258	...	...
	(*b*)	592	Slight improvement on A5 (*b*)	Not completely hardened. See Figs. 2 and 3
	(*c*)	534	...	
	(*d*)	426	...	
B2	(*a*)	258	...	...
	(*b*)	622	Fairly good. Similar to A10 (*b*)	Not completely hardened. See Figs. 2 and 3
	(*c*)	592	...	
	(*d*)	510	...	
B5	(*a*)	258	...	...
	(*b*)	661	Good fine fracture	Hardening not quite complete
	(*c*)	661	...	
	(*d*)	563	...	
B10	(*a*)	258	...	...
	(*b*)	661	Good fine fracture	Structure practically ideal. See Figs. 4 and 5. Fine martensite in tempered specimens
	(*c*)	661	...	
	(*d*)	592	...	
C1	(*a*)	258	...	...
	(*b*)	622	Fine conchoidal	Hardening not quite complete, but very nearly. See Fig. 6
	(*c*)	534	...	Ditto. See Fig. 3
	(*d*)	464	...	

[1] (*a*) As received.
(*b*) As hardened.
(*c*) Hardened and tempered at 600° C.
(*d*) „ „ „ 680° C.

TABLE II. (*continued*).

Mark.	State.[1]	Brinell Hardness.	Description of Fracture.	Description of Microstructure.
C2	(a)	258	...	...
	(b)	662	Good fine conchoidal	Ideal structure. Small austenite. See Fig. 7 (Plate XXXVI.)
	(c)	622	...	Fine martensite
	(d)	592	...	
C5	(a)	258	...	...
	(b)	661	Coarser. Galvanised appearance	Austenite crystals too large. Overheated slightly. See Fig. 8
	(c)	661	...	Coarse martensite in tempered specimens
	(d)	592	...	
C10	(a)	258	...	...
	(b)	661	Coarse. Worse than C5 (b)	Very large austenite grains. See Fig. 9
	(c)	661	...	Coarse martensite in tempered specimens. See Fig. 10
	(d)	661	...	
D1	(a)	258	...	...
	(b)	622	Good	Improperly hardened. See Fig. 6
	(c)	563	...	
	(d)	510	...	
D2	(a)	258	...	...
	(b)	661	Conchoidal, but dry	Large austenite grains. Evidently overhardened. See Fig. 11
	(c)	661	...	Coarse martensite in tempered specimens. See Fig. 12
	(d)	592	...	
D5	(a)	258	...	...
	(b)	661	Dry and cokey	Badly overheated. Intercrystalline constituent resembling eutectic formed. See Fig. 13
	(c)	661	...	Very coarse martensite in tempered specimens. See Fig. 14 (Plate XXXVII.)
	(d)	622	...	
D10	(a)	258	...	...
	(b)	661	Dry and cokey	Very badly overheated. Larger amounts of intercrystalline eutectic. Signs of fusion at crystal boundaries. See Fig. 15
	(c)	661	...	Very coarse martensite in which intercrystalline eutectic persists. See Fig. 16
	(d)	661	...	

[1] (a) As received. (b) As hardened. (c) Hardened and tempered at 600° C. (d) ,, ,, ,, 680° C.

CONSIDERATION OF RESULTS.

A study of the photomicrographs will show that the firs specimen to give a completely hardened structure is B10, hardened from 1250° C. after soaking for ten minutes (Fig. 4, Plate XXXV.).

The only other ideal structure is given by C2, *i.e.* 1300° C. for two minutes (Fig. 7, Plate XXXVI.).

1300° C. seems to be slightly high for hardening, unless the time of soaking is very carefully watched. Thus after one minute the steel is not hardened completely, while in five minutes crystal growth has taken place (Fig. 8). C10, hardened at 1300° C. for ten minutes (Fig. 9), shows enormous crystal growth. It is interesting to note that the structure develops on tempering into coarse martensite (Fig. 10), and this becomes more marked in the specimens hardened from 1350° C. D1, soaked at 1350° C. for one minute, is not completely hardened, while two minutes at this temperature produces large crystal growth (Fig. 11). This structure after tempering shows a very much more marked acicular structure. Soaking for five and ten minutes at 1350° C. (D5 and D10, Figs. 13 and 15, Plate XXXVII.) produces a very coarse structure, and a peculiar herring-bone constituent at the crystal junctions makes its appearance. In the tempered state these specimens show very much coarser martensite, and the eutectic constituent persists (Figs. 14 and 16).

The overheated specimens, especially D5 and D10, show a development of structure inside the crystals, and the interior of the crystals darkens rapidly on etching, in contradistinction to the very slow attack which takes place in sections possessing the small austenitic structure.

Certain specimens were etched in Yatsevitch's reagent (NaOH + H_2O_2). The herring-bone constituent is shown up in a marked fashion, and the etching plainly shows the increase in the amount of this constituent with higher temperatures. This constituent is clearly seen in Fig. 17, which is a photograph of the specimen hardened at 1350° C. for ten minutes, followed by etching in this new reagent.

According to Yatsevitch, this reagent attacks the complex carbides. Certainly, if a correctly hardened specimen is polished and etched in this reagent, the only markings which appear are a few black specks, which correspond to the brilliant white specks produced when etching is carried out in alcoholic 4 per cent. nitric acid. It will be found that such specimens which show a small-grained polygonal structure on etching in HNO_3 do not show up the crystal boundaries in Yatsevitch's reagent as the overheated

specimens do. It will be noticed that the herring-bone constituent in Fig. 17 is very similar to the eutectic found in cast high-speed steel.

The Brinell hardness figures of the tempered specimens throw an interesting light on the behaviour of the hardened and the unhardened specimens. In all cases where the specimens were completely hardened, the hardness drops only slightly, the lowest figure being 592, which is still a satisfactory cutting hardness, even after tempering at such high temperatures as 600° C. or 680° C.

The under-hardened specimens, as diagnosed by microscopic examination, lose their hardness rapidly on tempering. The over-hardened specimens, on the other hand, do not lose their hardness at all on tempering, under the conditions here described. As an example, the following three sets of figures may be compared :

	Brinell Hardness.		
	Over-hardened Steel D10.	Correctly hardened Steel C2.	Under-hardened Steel C1.
As hardened . . .	661	661	622
Tempered at 600° C. . .	661	661	534
,, ,, 680° C. . .	661	592	464

From an examination of the microstructures, the fractures, and the Brinell hardnesses, it would appear that a temperature of 1250° C. to 1275° C. for a suitable length of time gives the best results on the particular sections experimented with. This temperature appears desirable on account of the slightly longer time necessary for complete soaking. With the higher hardening temperatures, and the very much shorter time of soaking, the operation is decidedly dangerous, as a slight error in the time of soaking has a considerable effect in under- or over-hardening as the case may be.

A very important conclusion from this preliminary work is that *the Brinell hardness and the appearance of the fracture in the hardened state are no criterion of correct hardening.*

Section I.b.—*The Effect of Tempering J1 Steel at 600° C.*

Nine ½-inch cubes of similar steel were stamped F, F1, &c., to F8, and hardened as described in Section I.a.

The analysis of the material was:

	Per Cent.
Carbon	0·57
Silicon	0·09
Tungsten	13·78
Chromium	3·39
Manganese	0·43
Vanadium	0·19
Sulphur	0·05
Phosphorus	0·05

Since the mass of these specimens was about one-third of those dealt with in Section I.a, the hardening treatment adopted, in accordance with the results already obtained, was 1260° C. for two minutes. A micro-examination of specimen F proved that this treatment was satisfactory, the specimen showing the correct small austenitic structure.

Each of the specimens was found to possess a Brinell hardness of 661. They were then tempered in nitre at 600° C. for two minutes and the hardnesses redetermined. They were tempered again at various temperatures, 100° C., 200° C., &c., 680° C., and 750° C. for ten minutes, and retested for hardness. The specimens were retempered at the same temperatures as before, and hardnesses were again determined. The tempering was repeated for a further ten minutes, and the hardnesses were redetermined, so

Table III.

Mark.	Treatment.
F	No tempering
F1	Second tempering at 100° C. for 10 mins.
F2	,, ,, 200° C. ,,
F3	,, ,, 300° C. ,,
F4	,, ,, 400° C. ,,
F5	,, ,, 500° C. ,,
F6	,, ,, 600° C. ,,
F7	,, ,, 680° C. ,,
F8	,, ,, 750° C. ,,

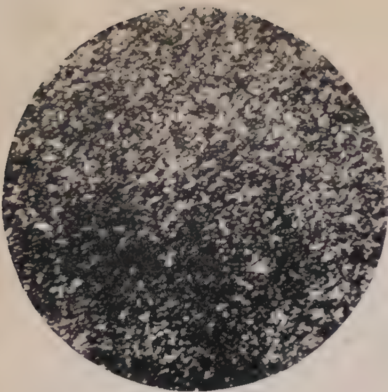

FIG. 1.—A10. Hardened 1200° C. ×10 mins.

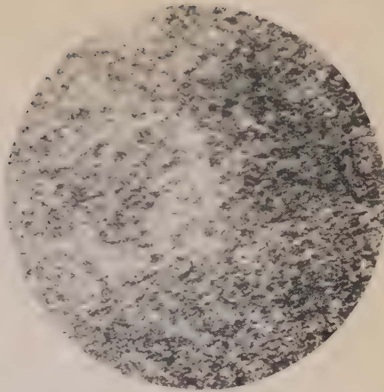

FIG. 2.—B1. Hardened 1250° C ×1 min.

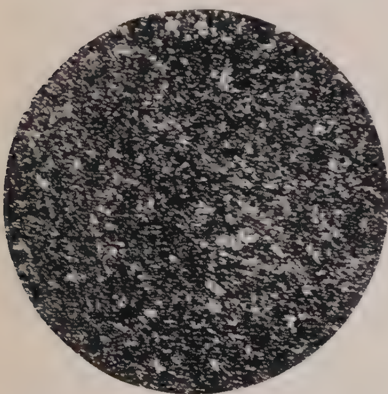

FIG. 3.—B1. Hardened 1250° C. ×1 min. Tempered 680° C.

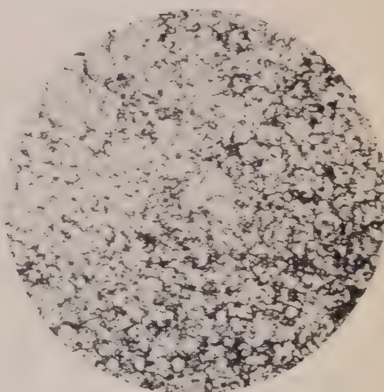

FIG. 4.—B10. Hardened 1250° C. ×10 mins.

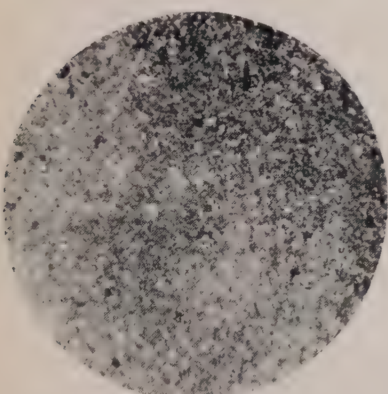

FIG. 5.—B10. Hardened 1250° C. ×10 mins. Tempered 600° C.

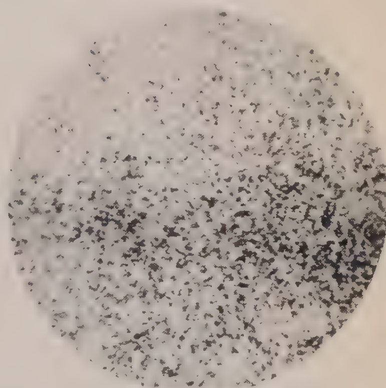

FIG. 6.—C1. Hardened 1300° C. ×1 min.

All the photomicrographs were taken at a magnification of 500 diameters, and have been reduced to $\frac{8}{11}$.

[*To face p.* 3

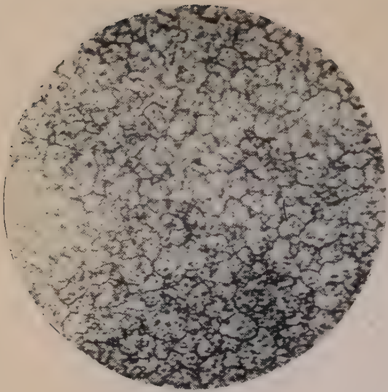

FIG. 7.—C2. Hardened 1300° C. ×2 mins.

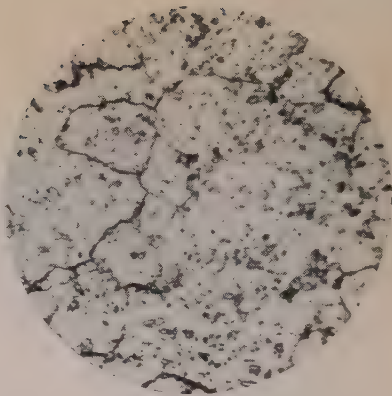

FIG. 8.—C5. Hardened 1300° C. ×5 mins.

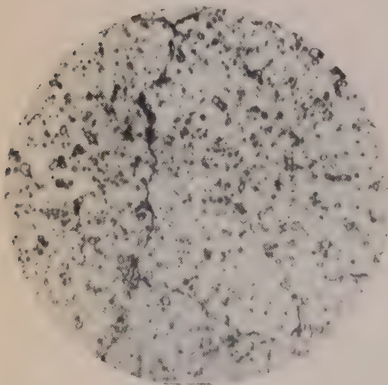

FIG. 9.—C10 Hardened 1300° C. ×10 mins.

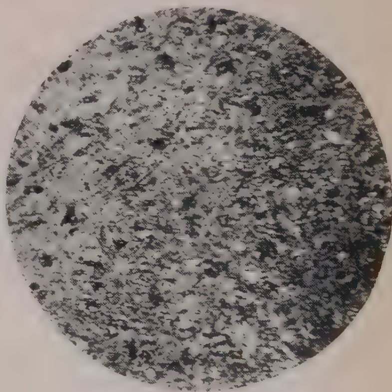

FIG. 10 —C10. Hardened 1300° C. ×10 mins. Tempered 600° C.

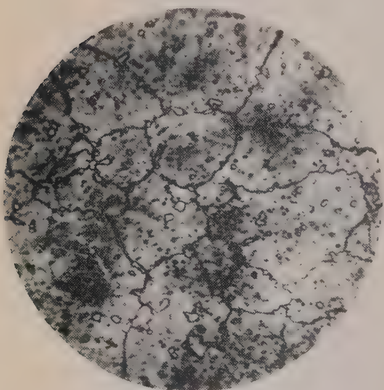

FIG. 11.—D2. Hardened 1350° C. ×2 mins.

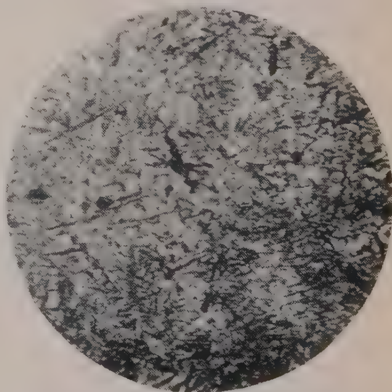

FIG. 12.—D2. Hardened 1350° C. ×2 mins. Tempered 680° C.

All the photomicrographs were taken at a magnification of 500 diameters, and have been reduced to $\frac{8}{11}$.

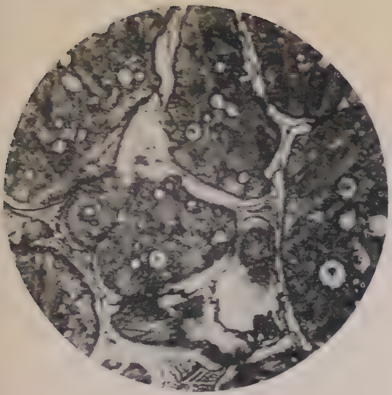

FIG. 13.—D5. Hardened 1350° C. ×5 mins.

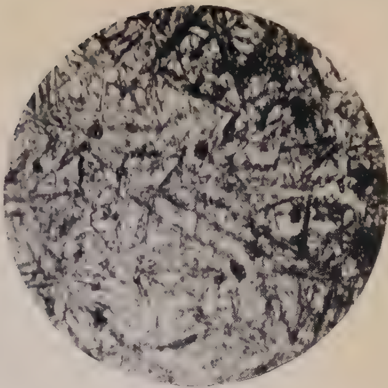

FIG. 14.—D5. Hardened 1350° C. ×5 mins. Tempered 600° C.

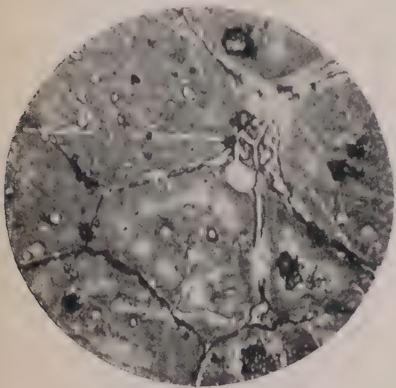

FIG. 15 —D10. Hardened 1350° C. ×10 mins.

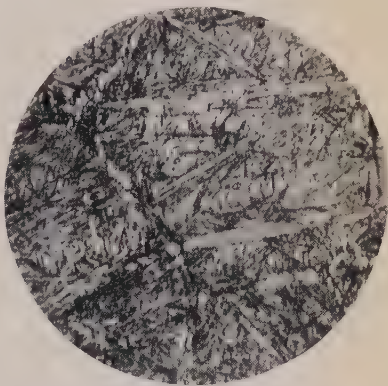

FIG. 16.—D10. Hardened 1350° C. ×10 mins. Tempered 600° C.

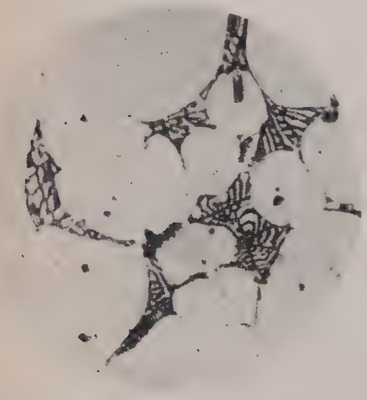

FIG. 17.—D10. Hardened 1350° C. ×10 mins. Etched Yatsevitch reagent.

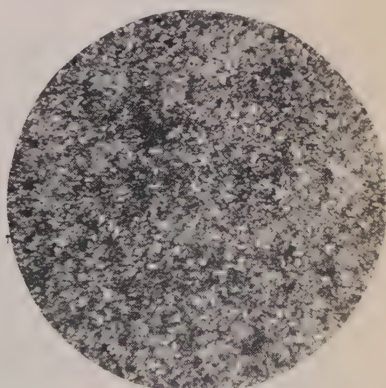

FIG. 18.—R1. Hardened 900° C. ×1 min.

All the photomicrographs were taken at a magnification of 500 diameters, and have been reduced to $\frac{8}{11}$.

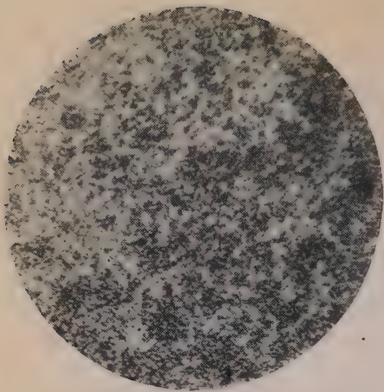

FIG. 19.—R10. Hardened 900° C. × 10 mins.

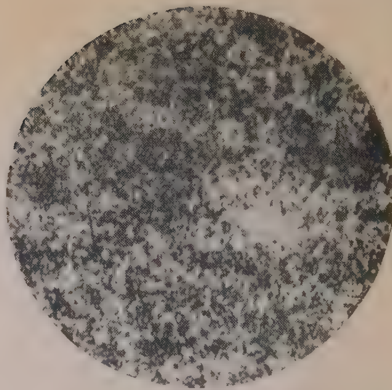

FIG. 20.—S5. Hardened 950° C. × 5 mins.

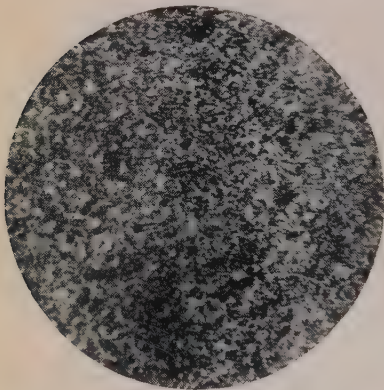

FIG. 21.—U10. Hardened 1050° C. × 10 mins.

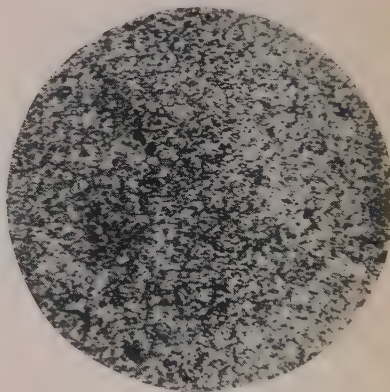

FIG. 22.—V10. Hardened 1100° C. × 10 mins.

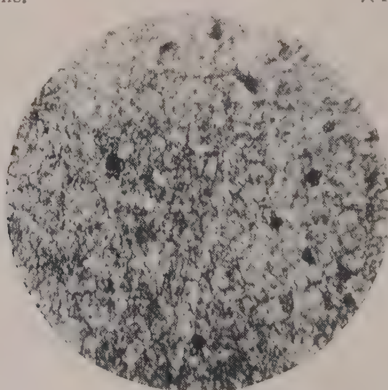

FIG. 23.—W10. Hardened 1150° C. × 10 mins.

All the photomicrographs were taken at a magnification of 500 diameters, and have been reduced to $\frac{8}{11}$.

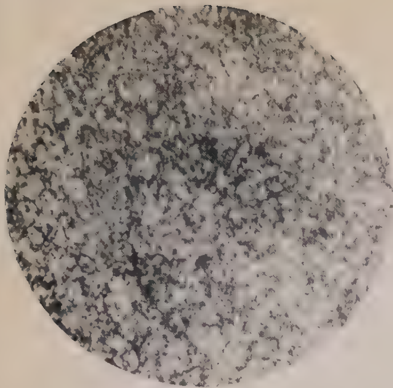

FIG. 24.—O10. Hardened 1200° C. ×10 mins.

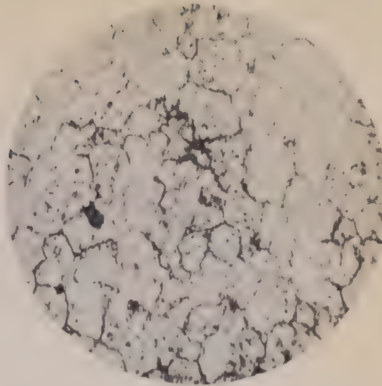

FIG. 25 —X1. Hardened 1250° C. ×1 min.

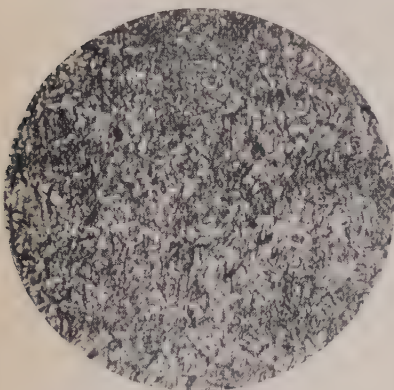

FIG. 26.—X1. Hardened 1250° C. ×1 min. Tempered 600° C.

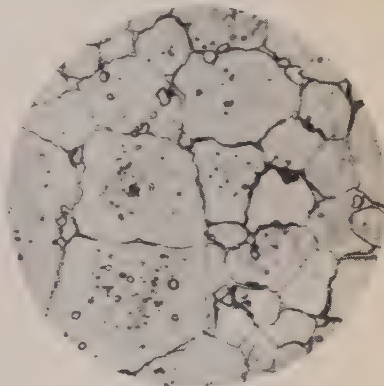

FIG. 27.—X5. Hardened 1250° C. ×5 mins.

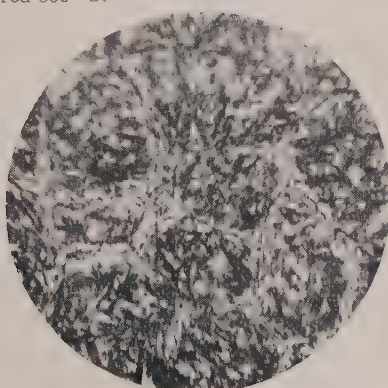

FIG. 28.—Y5. Hardened 1300° C. ×5 mins.

All the photomicrographs were taken at a magnification of 500 diameters, and have been reduced to $\frac{8}{11}$.

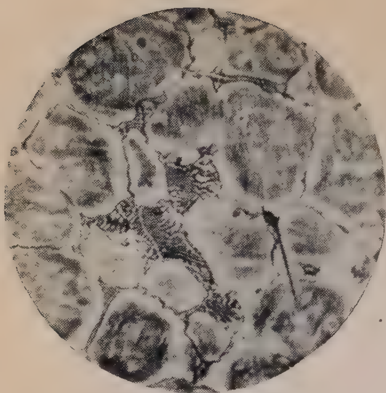

FIG. 29.—Z2. Hardened 1350° C. ×2 mins.

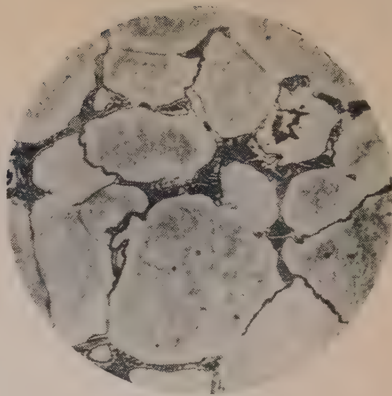

FIG. 30.—Z5. Hardened 1350° C. ×5 mins.

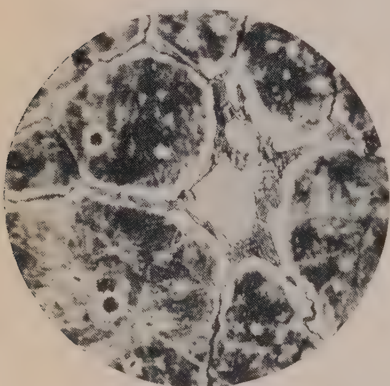

FIG. 31.—Z10. Hardened 1350° C. ×10 mins.

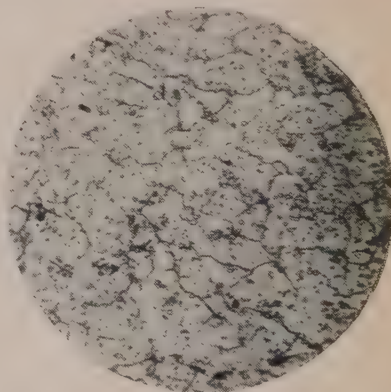

FIG. 32.—B Series. Hardened 1260° C. ×2 mins.

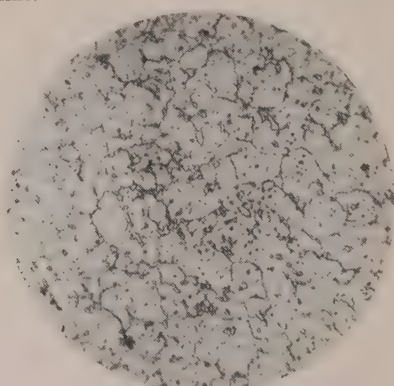

FIG. 33.—N Series. Hardened 1220° C. ×2 mins.

All the photomicrographs were taken at a magnification of 500 diameters, and have been reduced to $\frac{8}{11}$.

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that in all the specimens received thirty minutes' total tempering at their respective temperatures.

The treatments are given in Table III.; the results are shown in Table IV., and plotted in Fig. 34.

TABLE IV.

Treatment.	Mark.								
	F.	F1.	F2.	F3.	F4.	F5.	F6.	F7.	F8.
A.—After hardening at 1260° C. for two minutes only . .	661	661	661	661	661	661	661	661	661
B.—After hardening as *A* and tempering at 600° C. for two minutes . . .	...	592	576	592	592	586	592	592	596
C.—*B* after re-tempering at indicated temperature for ten minutes .	...	592	573	586	586	592	586	534	444
D.—*C* after re-tempering for a further ten minutes . . .	...	592	573	586	592	586	586	487	360
E.—*D* after re-tempering for a further ten minutes, making thirty minutes total . .	...	592	572	586	592	586	586	487	345

Observations.—These results show that tempering at 600° C. after hardening reduces the hardnesses uniformly, but that after this treatment tempering at any temperature up to and including 600° C. makes no appreciable difference to the hardness, as would occur to specimens which have not been tempered at 600° C. It is well known that the hardness drops on tempering at 400° to 500° C., and rises again on tempering at 600° C. only in specimens which have received the correct hardening treatment. Tempering at 680° C. produces a distinct drop in hardness, while at 750° C. this effect is considerable.

The important point brought out by these tests is that this material, after correctly hardening and tempering at 600° C. for

two minutes, appears perfectly stable as regards hardness at any

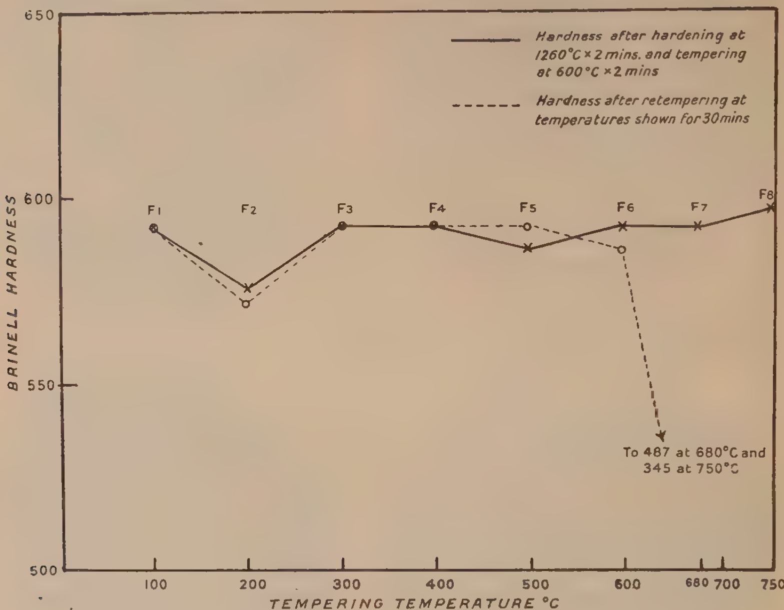

FIG. 34.—Effect of Tempering High-Speed Steel at 600° C.

temperature up to 600° C., since tempering for as long as thirty minutes did not diminish the hardness.

SECTION II.—*J2 Steel.*

The work on J2 steel followed the same lines as that on J1 steel described in Section I.A. The hardening technique was also similar, as the conditions were the same as those detailed above.

The essential difference in this section was the somewhat higher carbon content of the material, which had the following composition :

	Per Cent.
Carbon	0·76
Silicon	0·17
Tungsten	13·54
Chromium	3·23
Manganese	0·46
Vanadium	0·25
Sulphur	0·04
Phosphorus	0·05

The hardening treatments adopted are listed in Table V.

TABLE V.

Mark.	Temperature. ° C.	Complete Time of Soaking. Minutes.
R1	900	1
R2	,,	2
R5	,,	5
R10	,,	10
S1	950	1
S2	,,	2
S5	,,	5
S10	,,	10
T1	1000	1
T2	,,	2
T5	,,	5
T10	,,	10
U1	1050	1
U2	,,	2
U5	,,	5
U10	,,	10
V1	1100	1
V2	,,	2
V5	,,	5
V10	,,	10
W1	1150	1
W2	,,	2
W5	,,	5
W10	,,	10
O1	1200	1
O2	,,	2
O5	,,	5
O10	,,	10
X1	1250	1
X2	,,	2
X5	,,	5
X10	,,	10
Y1	1300	1
Y2	,,	2
Y5	,,	5
Y10	,,	10
Z1	1350	1
Z2	,,	2
Z5	,,	5
Z10	,,	10

Observations.—Brinell hardness tests, observations on fracture and microstructure, are given in Table VI.

TABLE VI.

Mark.	State.[1]	Brinell Hardness.	Description of Fracture.	Description of Microstructure.
R1	(a)	211	...	Normal annealed structure
	(b)	199	Raw	Similar to annealed specimen. See Fig. 18 (Plate XXXVII.)
	(c)	205		
	(d)	...	...	...
R2	(a)	211	...	...
	(b)	258	Raw	Similar to R1. See Fig. 18
	(c)	...	...	
	(d)	240	...	
R5	(a)	211	...	...
	(b)	409	Raw	Similar to R1. See Fig. 18
	(c)	...	...	
	(d)	321	...	
R10	(a)	211	...	...
	(b)	464	Raw	Slight evidence of troostite. See Fig. 19 (Plate XXXVIII.)
	(c)	409	...	Sorbitic
	(d)	343	...	
S1	(a)	211	...	...
	(b)	258	Raw	Sorbitic. See Fig. 18
	(c)	...	...	No micro-examination
	(d)	233	...	
S2	(a)	211	...	...
	(b)	375	Raw	Sorbitic. See Fig. 18
	(c)	345	...	No micro-examination
	(d)	...	...	
S5	(a)	211	...	...
	(b)	592	Raw	Troostitic. See Fig. 20
	(c)	...	...	Sorbitic
	(d)	375	...	
S10	(a)	211	...	...
	(b)	622	Raw	Troostitic. See Fig. 20
	(c)	...	...	Specimens lost
	(d)	...	...	
T1	(a)	211	...	...
	(b)	258	Raw	Sorbitic
	(c)	...	...	...
	(d)	...	...	...
T2	(a)	211	...	...
	(b)	409	Raw	Sorbitic
	(c)	...	...	...
	(d)	...	...	...
T5	(a)	211	...	...
	(b)	622	Slightly finer	Troostitic
	(c)	...	...	...
	(d)	...	...	...

[1] (a) As received.
(b) As hardened.
(c) Hardened and tempered at 600° C.
(d) ,, ,, ,, 680° C.

TABLE VI. (*continued*).

Mark.	State.[1]	Brinell Hardness.	Description of Fracture.	Description of Microstructure.
T10	(*a*)	211	...	...
	(*b*)	661	Fairly good	Troostitic appearance. See Fig. 20
	(*c*)	444	...	...
	(*d*)	...	...	...
U1	(*a*)	211	...	...
	(*b*)	240	Raw	Sorbitic
	(*c*)	...	...	...
	(*d*)	...	...	...
U2	(*a*)	211	...	...
	(*b*)	375	Raw	...
	(*c*)	...	...	...
	(*d*)	...	...	...
U5	(*a*)	211	...	...
	(*b*)	622	Finer	Troostitic
	(*c*)	...	...	...
	(*d*)	...	...	...
U10	(*a*)	211	...	...
	(*b*)	661	Fairly good	Troostitic appearance disappearing. See Fig. 21
	(*c*)	510	...	...
	(*d*)	444	...	...
V1	(*a*)	211	...	...
	(*b*)	258	Raw	Sorbitic
	(*c*)	...	...	...
	(*d*)	...	...	...
V2	(*a*)	211	...	...
	(*b*)	487	Raw	Sorbitic
	(*c*)	...	...	...
	(*d*)	...	...	...
V5	(*a*)	211	...	...
	(*b*)	661	Finer	Troostitic
	(*c*)	...	...	...
	(*d*)	...	...	...
V10	(*a*)	211	...	...
	(*b*)	694	Good	Approaching austenitic appearance. See Fig. 22
	(*c*)	563	...	...
	(*d*)	534	...	...
W1	(*a*)	211	...	...
	(*b*)	409	Crystalline	Sorbitic
	(*c*)	409	...	Sorbitic
	(*d*)	333	...	...

[1] (*a*) As received.
(*b*) As hardened.
(*c*) Hardened and tempered at 600° C.
(*d*) " " " 680° C.

TABLE VI. (*continued*).

Mark.	State.[1]	Brinell Hardness.	Description of Fracture.	Description of Microstructure.
W2	(*a*)	211	...	...
	(*b*)	592	Crystalline	Troostitic
	(*c*)	464	...	...
	(*d*)	426	...	...
W5	(*a*)	211	...	...
	(*b*)	661	Good	Austenitic
	(*c*)	592	...	...
	(*d*)	...	...	...
W10	(*a*)	211	...	...
	(*b*)	694	Good	Austenitic. See Fig. 23
	(*c*)	622	...	...
	(*d*)	563	...	...
O1	(*a*)	211	...	...
	(*b*)	464	Crystalline	Troostitic
	(*c*)	464	...	...
	(*d*)	391	...	...
O2	(*a*)	211	...	...
	(*b*)	661	Good	Troostite disappearing
	(*c*)	487	...	...
	(*d*)	...	...	...
O5	(*a*)	211	...	...
	(*b*)	661	Good, but slightly coarse	Austenitic
	(*c*)	592	...	...
	(*d*)	510	...	...
O10	(*a*)	211	...	...
	(*b*)	694	Good, but slightly coarse	Austenitic. See Fig. 24 (Plate XXXIX.)
	(*c*)	563	...	...
	(*d*)	534	...	Fine martensite
X1	(*a*)	225	...	Annealed structure
	(*b*)	622	Fairly good, but brittle	Large austenitic crystals. See Fig. 25
	(*c*)	622	...	Coarse martensite. See Fig. 26
	(*d*)	592	...	
X2	(*a*)	225	...	...
	(*b*)	661	Fine, but very dry	Large austenite
	(*c*)	661	...	Coarse martensite
	(*d*)	622	...	...
X5	(*a*)	225	...	...
	(*b*)	661	Very dry, but fine	Very coarse austenite. Signs of intercrystalline constituent. See Fig. 27
	(*c*)	...	...	Very coarse martensite
	(*d*)	622	...	

[1] (*a*) As received.
(*b*) As hardened.
(*c*) Hardened and tempered at 600° C.
(*d*) ,, ,, ,, 680° C.

TABLE VI. (*continued*).

Mark.	State.[1]	Brinell Hardness.	Description of Fracture.	Description of Microstructure.
X10	(*a*)	225	...	...
	(*b*)	661	Very dry	Very coarse martensite. Internal crystalline structure
	(*c*)	...	...	Very coarse martensite
	(*d*)	...	...	
Y1	(*a*)	225	...	...
	(*b*)	661	Fairly good	Small austenite
	(*c*)	...	...	...
	(*d*)	345	...	Sorbitic
Y2	(*a*)	225	...	...
	(*b*)	622	Good	Large crystals of austenite containing internal structure
	(*c*)	592	...	Coarse martensite
	(*d*)	622	...	
Y5	(*a*)	225	...	...
	(*b*)	592	Very brittle, finely crystalline	Very coarse crystals. Rapidly attacked. Intercrystalline constituent present. See Fig. 28
	(*c*)	...	...	...
	(*d*)	...	...	...
Y10	(*a*)	225	...	...
	(*b*)	592	Very brittle and finely crystalline	Similar to Y5. See Fig. 28
	(*c*)	...	...	...
	(*d*)	...	...	...
Z1	(*a*)	225	...	...
	(*b*)	661	Fine, but brittle	Large austenite
	(*c*)	622	...	Coarse martensite
	(*d*)	592	...	
Z2	(*a*)	225	...	...
	(*b*)	622	Crystalline	Large austenite and large masses of intercrystalline constituent. See Fig. 29 (Plate XL.)
	(*c*)	...	...	...
	(*d*)	...	...	...
Z5	(*a*)	225	...	...
	(*b*)	592	Very coarse and brittle	Enormous amount of intercrystalline constituent. See Fig. 30
	(*c*)	...	...	...
	(*d*)	...	...	...
Z10	(*a*)	225	...	...
	(*b*)	661	Very coarse and brittle	Enormous crystals and very large masses of intercrystalline constituent. See Fig. 31
	(*c*)	...	...	...
	(*d*)	...	...	...

[1] (*a*) As received.
(*b*) As hardened.
(*c*) Hardened and tempered at 600° C.
(*d*) ,, ,, ,, 680° C.

Consideration of Results.

A study of the photomicrographs shows that the first specimen to give a hardened structure is W5, hardened at 1150° C. after soaking for five minutes. There are signs in this specimen of an austenitic crystal structure. The latitude in hardening is comparatively wide, 1150° C. for ten minutes, 1200° C. for five minutes and ten minutes all giving similar results. The temperature of hardening for this material should not reach 1250° C., since soaking for only one minute produces a large structure, and specimens hardened at higher temperatures and for longer times show progressive crystal growth, which structure on tempering develops into coarser martensite than is desirable. Similar observations as regards overheating are noted with the higher carbon steel as with J1, the difference being, however, that the overheated structure is developed in the J2 steel at a considerably lower temperature.

The first indication of the intercrystalline eutectic constituent in J1 steel is found in the specimen hardened at 1350° C. for five minutes, while 1250° C. for ten minutes is sufficient to cause the commencement of its production in J2 steel. While it is not marked, it becomes very pronounced in Y5, hardened at 1300° C. for five minutes (Fig. 28, Plate XXXIX.).

As in the case of the J1 steel, the completely hardened specimens of J2 steel retain their hardness on tempering, while in those under-hardened the hardness is rapidly lost.

Conclusions.

The main conclusions to be drawn in comparing the results of the two steels are :

1. The increase in carbon content of 0·1 to 0·15 per cent. in a 14 per cent. tungsten high-speed steel causes a diminution in the temperature required for correct hardening, the reduction being something like 100° C.

2. The effect of temperature on the hardened structure is much more marked with the higher carbon steel, the production of an overheated structure being effected much more easily.

3. The same applies to the production of the intercrystalline

eutectic constituent, which appears to resemble closely the eutectic formed in high-speed steel cooled from fusion. The production of this constituent is apparently due to incipient fusion which takes place at the crystal boundaries.

4. The presence of this intercrystalline constituent appears to cause excessive brittleness in the hardened material.

5. The range of temperature and time for hardening the higher carbon steel is greater than for the lower carbon material. With the specimens experimented upon, between 1150° C. and just over 1200° C., and five to ten minutes, according to the temperature, appears suitable for J2 steel, whereas with the J1 steel 1250° C. or just over seems to give the best results. If this temperature is exceeded by any appreciable amount, the time necessary is reduced to such a short period as to reduce the factor of safety in commercial hardening.

6. The higher carbon material is considerably more brittle when hardened.

7. A peculiar microstructural effect is evident in the specimens which are not quite hardened—that is, those which, though showing a high hardness figure after hardening, lose their hardness rapidly on tempering. For example, it was noted that (A2), (B1), and (D1) in the J1 series, and (S5), (T10), and (W2) in the J2 series, which show almost a troostitic effect, with no evidence of crystal boundaries, possess this peculiarity.

A stage further in the hardening causes the troostite to disappear gradually, as shown in (C1) (Fig. 6, Plate XXXV.) in the J1 series, and in (S10) and (O2) in the J2 series. The next step is the reduction of this constituent with the initial formation of the austenite crystal boundaries (V10) (Fig. 22, Plate XXXVIII.). The production of this troostitic material appears to coincide with the so-called carbon hardening of the steel, which takes place before the true red-hardness properties of the material are developed.

8. The conclusion already arrived at with the J1 series is confirmed in this higher carbon series—namely, that hardness and fracture in the hardened state are no criterion of the material having been correctly hardened to produce the red-hardness property.

PART II.

THE EFFECT OF TIME AND TEMPERATURE OF HARDENING AND TEMPERING ON THE HARDNESS OF J1 AND J2 STEELS.

SECTION I.—*J1 Steel.*

The material used for these investigations was similar to that employed in Part I.; the actual composition of the steel was as follows:

	Per Cent.
Carbon	0·57
Silicon	0·10
Tungsten	13·78
Chromium	3·39
Manganese	0·43
Vanadium	0·19
Sulphur	0·05
Phosphorus	0·06

The bars of ½ inch square section were received in the annealed condition, and the specimens used were cut off so as to form pieces ½ inch cube, weighing approximately 18 grammes.

Heat Treatment.—The specimens were hardened, four at a time, in a Brayshaw gas-fired furnace, the four specimens being spaced out on a small firebrick. The temperature of the brick was taken before each batch of cubes was inserted into the furnace, by means of a carefully calibrated platinum-platinum-rhodium thermocouple. The specimens on removal from the furnace were cooled in a medium air-blast.

Tempering was carried out at the temperatures and for the times stated, the specimens of each batch tempered at one temperature being treated together and each being taken out after its own allotted time. Thus, six specimens would be placed together, suitably separated, in the tempering medium, and one taken out every minute up to five minutes, the last one being allowed to remain ten minutes.

Tempering up to and including 300° C. was carried out in an oil-bath, and above that temperature in a nitre bath, the former being suitably controlled by a base metal thermocouple, and the latter by a platinum-platinum-rhodium couple.

Micro-Examination.—Micro-examination was carried out on samples from the various batches after hardening to ensure that

each batch had received the same hardening treatment, and one specimen was kept in the hardened state for reference. Examination of the tempered specimens has not yet been made, but it is intended to do this at a future date.

Hardness Tests.—After hardening and tempering, the specimens were lightly ground (wet) so as just to remove the scaly surface, and then polished up to the 000 emery-paper to facilitate accurate readings. Brinell hardness determinations were then made. The impressions were produced by means of an Alpha Aktiebolag hydraulic machine, which had been carefully calibrated against a standard Avery dead-weight machine. A $\frac{1}{4}$ inch diameter ball was used with a load of 1210 kilos, this combination of ball-size and load producing impressions geometrically similar to those obtained by the standard practice of a 10-millimetre ball and 3000-kilos load. The small ball was used on account of the great hardness of the specimens, much sharper impressions being obtained by this means. The impressions were read across two diameters at right angles to each other with a Cambridge measuring microscope. The ball was carefully measured before use in every case, and was changed repeatedly in order that inaccuracies due to permanent deformation of the ball should not arise.

It is intended at a later date to carry out hardness determinations on the specimens by means of the Rockwell and the Vickers machines.

Scheme of Research.—Five series of specimens of J1 steel are being investigated; in the first four series the hardening temperature has been kept constant, and only the time of soaking varied from one to eight minutes, while in the last series the hardening temperature has also been increased.

The following are the hardening treatments used:

Series.	Temperature of Hardening. ° C.	Time of Soaking (Minutes).
A	1260	1
B	1260	2
C	1260	4
D	1260	8
E	1300	4

It will be noted that the hardening temperature 1260° C. has been adopted in most cases, as this was the best temperature indicated in the preliminary investigations described in Part I. The above treatments were designed so that Series A were not completely hardened, Series B were just completely hardened, and Series C, D, and E represented successive stages of over-hardening. Micro-examination of representative samples from each series showed that these conditions had been attained.

The Brinell hardness results of Series B, the only one completed at the moment, are given in Table VII. There are indications that the other series give somewhat different results, and should therefore be extremely interesting.

TABLE VII.—*Brinell Hardness of Series B Hardened at* 1260° *C. and Soaked for Two Minutes.*

Series Mark.	Tempering Temperature. ° C.	Tempering Time (Minutes).						
		0.	1.	2.	3.	4.	5.	10.
B	0	670	...	...	...	...	...	...
B1	100	...	660	660	660	650	660	650
B2	200	...	650	632	632	650	640	650
B3	300	...	640	632	640	632	632	632
B4	400	...	600	592	592	600	585	585
B5	500	...	600	592	592	592	585	600
B6	600	...	615	624	624	632	607	600
B7	680	...	624	615	592	585	578	540
B8	750	...	592	455	440	450	405	375

The data given in the above table have been plotted in the form of two sets of curves ; the first (Fig. 35) shows the effect of time on hardness with constant temperature, while the second (Fig. 36) shows the effect of temperature with constant time (Plate XLI.).

The two sets of curves have been combined in a chart (Fig. 37, Plate XLII.) on which have been drawn lines of equal hardness, in a similar way to that adopted in isothermal diagrams. It shows at a glance the different zones of hardness produced by a combination of time and temperature of tempering. It cannot be regarded as absolutely correct, but it is claimed that it does show, in a general way, the variations in hardness which a piece of high-speed steel undergoes when hardened as described.

Examination of "Hardness Map" of Series B.

Fig. 37 shows that there are definite signs of secondary hardening in the neighbourhood of 600° C., although the hardness produced by tempering never reaches or exceeds the original hardness in the hardened state. It is evident, however, that the series had been satisfactorily hardened, and this was confirmed by micro-examination of specimen B (Fig. 32, Plate XL.); a small austenitic structure, considered to be representative of correct hardening, is to be seen.

In the first place, the hardness of the specimens without tempering is 670. Following the diagram from the time ordinate in the direction of increasing temperature, the hardness gradually drops to a minimum, represented by a "valley," at the temperature range 400° to 500° C. A rise leads up to the secondary hardening zone, in the neighbourhood of 600° C., represented by a ridge, which, however, is not of uniform height. Above 600° C. the hardness falls away rapidly with increasing temperature. These effects for particular tempering temperatures are shown in diagrams *i*, *j*, *k*, *l*, *m*, and *n*, Fig. 36, which represent the contours cut by planes along the 1, 2, 3, &c., minute ordinates.

The diagram (Fig. 35, *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*) is also very interesting. Diagrams *d* and *e* show that the hardness reaches a minimum between 400° and 500° C. in the neighbourhood of five minutes. It should be noted that tempering at 600° C. (diagram *f*) does not produce such a marked softening; after one minute's tempering the hardness drops sharply, but further tempering causes a rise, which reaches a maximum at four minutes, producing the greatest hardness after tempering of all the treatments. Further tempering up to ten minutes produces a slow decrease, but there are indications that the material is nearly stable.

Consideration of the Results of Series B.

The present theory of the secondary hardening phenomena of high-speed steel attributes this hardening during tempering to the production of martensite, which is somewhat harder than the austenite produced during hardening.

In the steels under review (heated to 1260° C. for two minutes and cooled in an air-blast) the maximum secondary hardening

effect occurs at 600° C., but there are signs of secondary hardening at 500° C., if the tempering time is long enough. The curve shows that in the material tempered at 600° C. the maximum breakdown of austenite to martensite, causing maximum secondary hardening, occurs after tempering for four minutes. Longer tempering times produce a slight breakdown of this martensite.

Section II.—*J2 Steel.*

Section II. contains the results of similar work to that described in Section I. carried out on the higher carbon steel J2.

The composition of the material was :

	Per Cent.
Carbon	0·75
Silicon	0·15
Tungsten	13·71
Chromium	2·80
Manganese	0·50
Vanadium	0·35
Sulphur	0·05
Phosphorus	0·06

The temperature of hardening for this Series N was 1220° C. and the time two minutes, these being decided upon after consideration of the results obtained in Part I., Section II. A photomicrograph representing the hardened structure is shown in Fig. 33 (Plate XL.). The hardness results of Series N are given in Table VIII.

Table VIII.—*Brinell Hardness of Series N Hardened at* 1220° *C. and Soaked for Two Minutes.*

Series Mark.	Tempering Temperature. ° C.	Tempering Time (Minutes).						
		0.	1.	2.	3.	4.	5.	10.
N1	0	636	...	...	...	...	...	...
N2	100	...	628	628	634	634	634	644
N3	200	...	601	604	602	608	608	592
N4	300	...	596	604	578	592	592	580
N5	400	...	578	578	563	550	563	580
N6	500	...	572	540	556	534	534	556
N7	600	...	585	562	586	592	608	611
N8	680	...	628	645	652	661	661	604
N9	750	...	578	510	500	487	487	441

The curves of hardness showing the effect of tempering time with constant temperature and of tempering temperature with constant time are given in Figs. 38, *a* to *h*, and 39, *i* to *n* (Plate XLIII.), while the hardness chart, formed from a combination of these sets of curves, is given in Fig. 40 (Plate XLIV.).

Examination of the Hardness " Map " of Series N.

An examination of the map of Series N (Fig. 40) shows that in certain respects it is similar to that already described for Series B (Fig. 37).

First, it will be noticed that the initial hardness of the material is lower than that of the B Series. Secondly, the hardness drops gradually from the time ordinate until a minimum zone is reached in the neighbourhood of 500° C. Thirdly, the hardness then rises again to figures which are considerably higher than the original hardness in the hardened state, and represented by the ridge running from four minutes at 680° C. to ten minutes at 600° C. This is the maximum secondary hardness.

In the lower ranges of tempering time the maximum secondary hardening takes place at 680° C. up to five to six minutes, while at ten minutes the maximum effect takes place at 600° C. The curve *f*, Fig. 38, shows that the hardness drops rapidly when the steel is tempered at 600° C. up to three minutes and then rapidly hardens up again, until at ten minutes the material is harder than it was originally, but even at this point it is not stable.

There are signs of secondary hardening at 500° C. and 400° C. if the tempering time is long enough (*d* and *e*). There is only a slight drop in the curve *g* before the secondary hardening effect takes place.

Further series are being investigated, but at the moment all that can be said is that the initial hardening treatment has a profound effect on the behaviour of high-speed steel during tempering.

The material used in these researches has been prepared and kindly supplied to the author by Messrs. Wm. Jessops & Sons, Ltd., Brightside Works, Sheffield, to whom the thanks of the author are due.

The whole of the research has been carried out in the Research Laboratories of the Birmingham Small Arms Co., Ltd., Birmingham, and the author wishes to thank this Company for allowing the results to be published.

The author also desires to place on record his acknowledgments and thanks to his assistants, who have done a large proportion of this work, more especially to Mr. F. Blakey and Mr. S. C. Wilsdon.

DISCUSSION.

Mr. Hugh O'Neill (Manchester) said the author realised as well as he did that in the use of a steel ball on hardened specimens the Brinell results above 600 were not of any very great value; personally, he did not consider they were of any value at all. The impressions were shallow, and their diameter of curvature was nothing like that of the ball before it was loaded. He had recently been making some tests with a diamond ball of 1 millimetre diameter, on a hard specimen of steel (it was actually the 100 hard standard block of the Shore scleroscope, which was fairly uniform across the surface). The Brinell results with a steel ball gave a hardness figure of 670, but the results with the diamond ball on the same steel, using the standard loading (30 kilogrammes with a ball of 1 millimetre diameter) gave a Brinell hardness number of 875. Existing evidence showed that against eutectoid steel hardened right out an ordinary steel ball took on a flat when loaded at 3000 kilogrammes of about 0·03 millimetre in depth. That gave some idea of the shallowness of the impression, which consequently gave an unduly low hardness figure.

Mr. Harry Brearley (Member of Council) thought the paper could only be discussed in detail by those actively engaged in the kind of work undertaken by the author. When he read the paper it made an extremely favourable impression on him. He had always felt that the large amount of money spent many years ago, and probably still being spent, in making machining tests with tools that had been hardened in the smith's hearth, was mainly wasted and might have been applied to better purposes. He thought the methods of indirectly determining the efficiency or the usefulness of high-speed steels adopted by the author were likely to lead to good results. He desired to ask the author whether he found that a treatment of tools based on observations such as were given in the paper led in service to satisfactory results.

Professor Thomas Turner (Member of Council) congratulated the author on his having been able to present such a mass of detail in a way which rendered it clear and easily understood, and on his adoption of the geographical method of representation, by which it was possible to see at a glance the hardness of the various samples of steel, and how they were affected by time and temperature. He felt sure that the members of the Institute would benefit considerably by having available the results given in the paper.

Colonel N. T. Belaiew, C.B. (London), referring to the light eutectoid constituent which appeared so clearly in some of the figures—for

instance in Fig. 17—said he understood from that figure that in that particular case the quenching temperature rose to 1350° C., and he asked how close that temperature was to the fusion temperature.

Mr. A. R. Page, in reply to Mr. O'Neill's remarks, said he realised that the ball testing of very hard materials did not give true figures of hardness, but in the research he had used a small ball and a correspondingly small load, so that the impressions obtained were not nearly

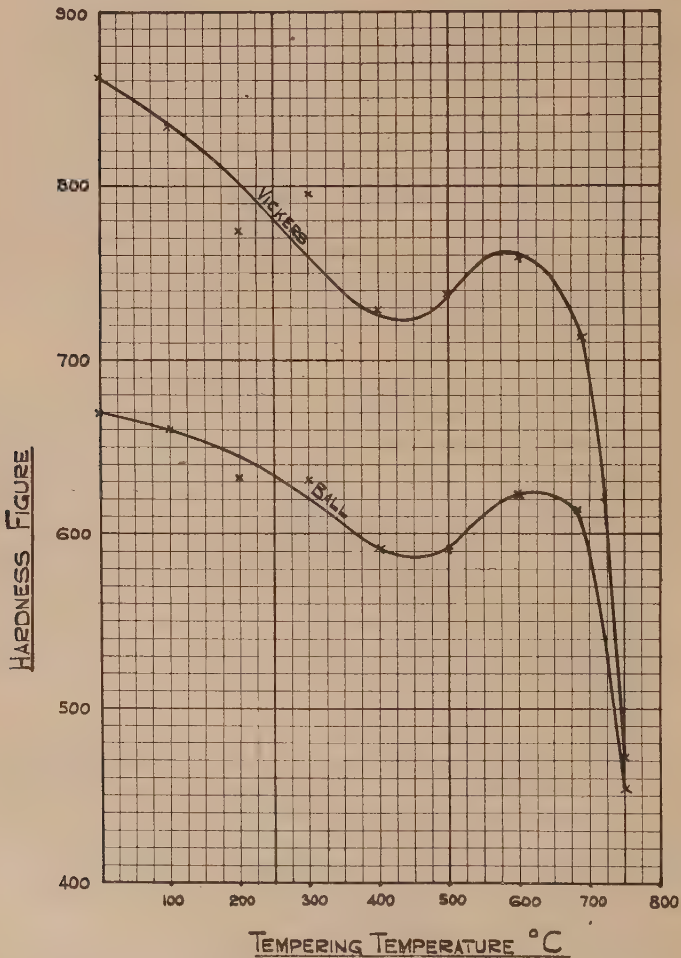

Fig. A.—Comparison of the Results obtained by Brinell and Vickers' Hardness Testing Machines.

so shallow as those which would be obtained with a 10-millimetre ball and 3000 kilogrammes, and the impressions had also more sharply defined edges, which facilitated measuring. He was very much interested in the comparative hardness figures of a steel which gave 670 and 875 when tested with a steel and a diamond ball respectively, as they confirmed figures which he had obtained with a diamond pyramid on a Vickers' machine. Although the diamond ball did give very much higher hardness figures than those obtained by the steel ball method, the hardness maps which were produced by the two methods were similar in design.

Considering, for example, the curve shown in Fig. 36 (*j*) (J1 steel tempered for 2 minutes at different temperatures), if the same tests were made with the Vickers' machine a curve something like that shown in Fig. A would be obtained. The same type of curve exactly was produced, but the differences in the higher hardnesses were magnified. At the lower hardnesses, say about 450, the two curves became coincident. He thought, therefore, the ball method of testing did give some information; it gave an idea of what was happening, provided, of course, that the ball test was carried out very carefully. With reference to Mr. Brearley's remarks, his experience in practice had confirmed some of the results described in the paper. The research was, of course, by no means finished; it had really only reached a preliminary stage. He hoped eventually to correlate the results with the actual behaviour of tools treated under definite conditions. In reply to the point raised by Colonel Belaiew, there was no doubt that 1350° C. was getting very near to the fusion temperature. As a matter of fact the specimens hardened at 1350° C. were fused on the outside, and, as was evident from the photomicrographs, fusion had commenced at the crystal boundaries.

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Iron and Steel Institute.

THE RATIO OF THE TENSILE STRENGTH OF STEEL TO THE BRINELL HARDNESS NUMBER.*

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Introduction.

Ever since the introduction of the Brinell hardness test, it has been held that there is a more or less constant relation between the ultimate tensile strength of steels and their Brinell hardness number. It has never been claimed that the ratio of these quantities is exactly constant; on the contrary, there is general agreement that it is slightly different for different classes of steel, but on the question of the magnitude of these differences, and of the degree of variability of the ratio for a given class of steel, there is a marked divergence of opinion.

The Brinell hardness test as carried out in practice is an empirical and arbitrary test. Investigation of the ratio of tensile strength to Brinell hardness number is therefore essentially a statistical problem. A fundamental connection between results of ball hardness tests and tensile tests may be, and has been,[1] sought; but there is not much likelihood that theoretical considerations will reveal the best working value of the ratio of tensile strength to Brinell hardness number, or indicate the extent of the numerical variations to be expected in it.

A difficulty which arises in treating any statistical problem is the necessity of securing a large mass of reliable data to work on. The results which have accumulated during the last few years at the Research Department, Woolwich, form a contribution to the total data necessary, and they are now put forward, summarised and discussed in conjunction with results derived from other sources.

* Communication from the Research Department, Woolwich; received March 6, 1926.

The accuracy of the value of the ratio of ultimate tensile strength to Brinell hardness number is dependent on:

1. The accuracy of measurement of maximum load in tension. This is not subject to serious error, provided that the testing machine has been properly calibrated, but premature failure of a test-piece due to flaws or inclusions results in a low value of the ratio.

2. The accuracy of the Brinell hardness number determined with a 10-millimetre ball and 3000-kilogramme load. Even though the hardness testing machine has been properly calibrated and the impression accurately measured, the Brinell hardness number is liable in practice to errors which may arise, mainly, from two causes:

(*a*) Too rapid an application of the load, resulting in momentary overloading, a hardness number which is too low, and a ratio which is too high.

(*b*) Too brief an application of the load, resulting in a hardness number which is too high and a ratio which is too low.

Of these causes of error, (*a*) is the more commonly overlooked, and, with certain types of machine, is by far the more difficult to guard against; the error introduced by (*b*) is generally small, since the time of application of the load is rarely less than fifteen seconds.

3. Identity of material on which hardness and tensile tests are carried out. This point has frequently been overlooked, and the fact that hardness tests have been made on material adjacent to the tensile test-piece, or even on material "which has had the same treatment," is responsible for many abnormal tensile-Brinell ratios contained in published reports.

Results obtained in the Research Department, Woolwich.

In all the tests carried out in the Research Department, Woolwich, the following conditions were observed:

1. The Brinell hardness tests were made at not less than three positions along the length of at least one ground and polished face of a bar of rectangular section, from which the test-piece was subsequently turned.

2. The tests were made either in an Amsler ball-hardness testing machine or in a single-lever testing machine.

3. A ball of 10 millimetres diameter was used under a load of 3000 kilogrammes. The load was applied gradually, and held for at least thirty seconds. In the single-lever machines the balance was approximately adjusted at a lower load, the jockey weight was then moved slowly to the necessary position, held there for thirty seconds, and slowly rolled back to avoid all oscillation of the beam with the full load on. The impressions were measured with a measuring microscope fitted with a vertical illuminator, and reading to 0·001 millimetre.

4. The test-bar was then turned to a tensile test-piece (usually 0·564 inch in diameter) and tested in a single-lever testing machine (Buckton 30-ton or Avery 15-ton). All machines used, including the hardness testing machine, were calibrated several times during the period in which the tests were being made; the error in the loads measured throughout the tests probably never exceeded 1 per cent., and was usually much less than that figure.

Tests were made on medium-carbon steels in the annealed and heat-treated conditions, and on oil-hardened and tempered nickel, nickel-chromium, and other alloy steels. Results were first classified according to (1) composition and hardness, (2) composition and yield ratio (Table I., p. 340). A preliminary examination of the figures showed that between certain limits the hardness and the yield ratio of the steel had a smaller effect on the value of the tensile-Brinell ratio than had been expected, and it appeared to be justifiable to combine all the results on heat-treated alloy steels with a Brinell hardness number between 200 and 349 in one diagram, Fig. 1. It is evident that grouping by steps of 0·001, or less than 0·5 per cent., is rather too fine; groups of double the width gave the smooth curve, Fig. 2.

The average results of such a set of observations as this can be expressed in a number of different ways, *e.g.*:

1. The arithmetic mean. This may give too much weight to occasional very high or very low values.

2. The predominant value or "mode"—*i.e.* the value which occurs most frequently.

3. The median—*i.e.* the magnitude above and below which there are an equal number of results.

These figures are not of much value without some measure of the dispersion or scattering. When a comparatively small number of results is being dealt with, this is best obtained by

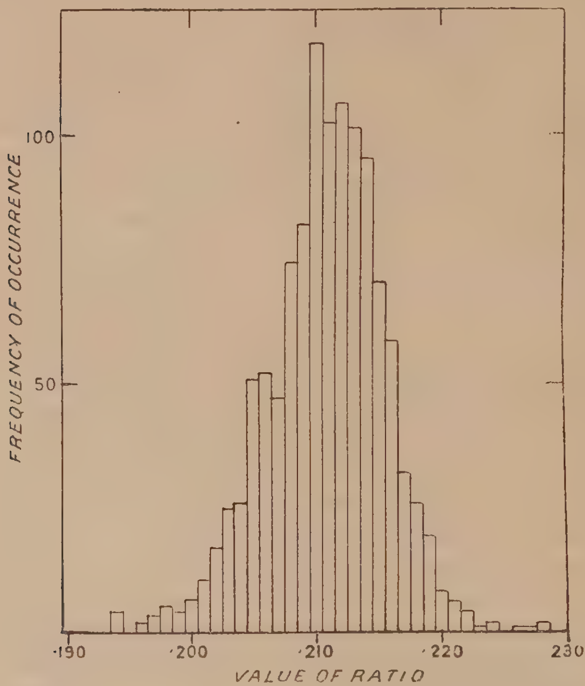

Fig. 1.—Frequency of Occurrence of Different Values of the Ratio of Tensile Strength to Brinell Hardness Number for 1161 Heat-Treated Alloy Steels (Table II.).

means of the "quartiles," or quantities one-quarter and three-quarters of the way up the series of observations arranged in ascending order of magnitude. The simplest measure of dispersion is half the distance between the quartiles, or "quartile deviation." Another quantity used to define dispersion is the "standard deviation," or "root mean square." If k is equal to the difference between the arithmetic average and any individual observa-

tion, and n the total number of observations, then the standard deviation is

$$\sigma = \sqrt{\frac{\Sigma(k^2)}{n}}.$$

In a symmetrical group of observations the arithmetic average, the mode, the median, and the mean of the quartiles are coincident,

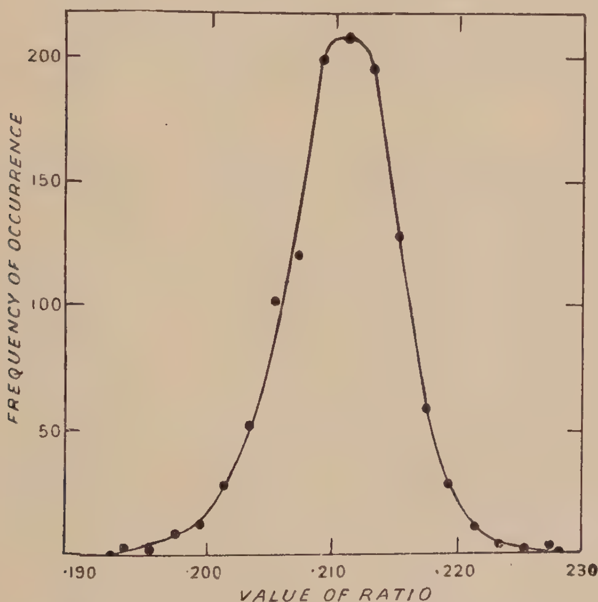

FIG. 2.—Frequency of Occurrence of Different Values of the Ratio for 1161 Alloy Steels (Table II.). Results grouped in steps of 0·002.

while the quartile deviation is equal to the "probable error"—a convenient but possibly misleading term, which, with the average, defines a range of values such that it is just as likely as not that a single observation will be within this range as outside it.* The probable error, r, is equal to $0{\cdot}6745\sigma$, or approximately $\frac{2}{3}\sigma$.

* Thus the statement (Table I.) that the probable value of the ratio is $R \pm r$, means that R is the average, and that the probability is $\frac{1}{2}$ (*i.e.* it is just as likely as not) that the true value lies between $R + r$ and $R - r$.

TABLE I.—*Value of the Ratio of Tensile Strength to Brinell Hardness Number for Steels Classified according to Composition, Hardness, and Yield Ratio.*

Type of Steel.	Brinell Hardness Number.	Number of Steels.	Arithmetic Average.	Probable Value (one-half of the values lie between these limits).	Yield Ratio.	Number of Steels.	Arithmetic Average.	Probable Value (one-half of the values lie between these limits).
Carbon steel (carbon about 0·4 per cent.), annealed or oil-hardened and tempered.	Under 150	24	0·223	0·223 ± 0·005	Under 0·5	50	0·223	0·224 ± 0·004
	150 to 174	96	0·218	0·218 ± 0·003	0·5 to 0·6	114	0·217	0·217 ± 0·003
	175 ,, 199	94	0·218	0·217 ± 0·004	0·6 ,, 0·7	70	0·217	0·217 ± 0·004
	200 ,, 249	34	0·216	0·215 ± 0·004	0·7 ,, 0·8	12	0·217	0·216 ± 0·003
					0·8 ,, 0·9	2	0·212	...
		248				248		
Nickel steels (mostly containing carbon about 0·35 per cent. and nickel 3 to 4 per cent.), oil-hardened and tempered.	Under 200	27	0·216	0·215 ± 0·004	Under 0·6	13	0·215	0·215 ± 0·006
	200 to 249	176	0·211	0·211 ± 0·003	0·6 to 0·7	94	0·212	0·213 ± 0·004
	250 ,, 299	23	0·210	0·210 ± 0·002	0·7 ,, 0·8	86	0·212	0·212 ± 0·003
	300 ,, 349	3	0·211	...	0·8 ,, 0·9	34	0·210	0·210 ± 0·002
					0·9 and over	2	0·209	...
		229				229		
Nickel-chromium and alloy steels other than nickel steels, oil-hardened and tempered.	Under 200	52	0·213	0·213 ± 0·004	Under 0·6	36	0·216	0·216 ± 0·004
	200 to 249	513	0·211	0·211 ± 0·003	0·6 to 0·7	117	0·213	0·213 ± 0·003
	250 ,, 299	363	0·211	0·211 ± 0·003	0·7 ,, 0·8	327	0·211	0·211 ± 0·003
	300 ,, 349	83	0·210	0·210 ± 0·004	0·8 ,, 0·9	428	0·210	0·210 ± 0·003
	350 ,, 399	31	0·212	0·212 ± 0·002	0·9 and over	147	0·210	0·210 ± 0·003
	400 ,, 449	13	0·213	0·213 ± 0·003				
		1055				1055		

The averages given in Table I. are the arithmetic average and the probable value—*i.e.* the mean of quartiles and quartile deviation.

An examination of the 1161 results obtained on heat-treated alloy steels of hardness 200 to 349 is given in Table II. The averages are in good agreement, and so also are the values of the probable error deduced from the quartile deviation and from the standard deviation, showing that the figures form a symmetrical group subject to the normal law of error; this is confirmed by the good agreement between the expected distribution of results calculated from the probable error and the actual distribution.

The probable error in these determinations of the ratio happens to be small, since the tests were made systematically under standard conditions on material which was for the most part uniform. It could, no doubt, be made much smaller if extreme care were taken to ensure that the hardness number adopted in the calculation expressed the hardness of the material exactly at the position where fracture subsequently occurred in the tensile test. A series of tests made under "workshop" conditions, the hardness impressions being made in an Alpha press on filed surfaces on the outsides of billets from which the tensile test-pieces were taken, and measured to 0·05 millimetre, gave, for carbon steel of hardness 150 to 200, a probable value of the ratio $0{\cdot}231 \pm 0{\cdot}011$. The comparative effect of "probable errors" of 0·003 and 0·010 respectively on the distribution of results is shown graphically in Fig. 3 (p. 344).

The results given in Tables I. and II. were obtained indiscriminately from longitudinal and transverse tests, 75 per cent. of the tests on carbon steel and 40 per cent. of the tests on alloy steel being on longitudinal test-pieces. This has some effect in flattening the maximum, since the ratio deduced from transverse tests is slightly less than that obtained from longitudinal tests. The difference in the average of the ratio based on longitudinal and on transverse tests (about 0·002 for alloy steels, and perhaps a little more for carbon steels) was, however, too small to necessitate separate treatment of the two sets of results.

TABLE II.—*Value of the Ratio of Tensile Strength to Brinell Hardness Number for Heat-Treated Alloy Steels of Hardness* 200 *to* 349.

Ratio.	Number of Occurrences. y.	Distance from Origin. x.	$xy \times 10^3$.	$x^2y \times 10^6$.	Ratio.	Number of Occurrences. y.	Distance from Origin. x.	$xy \times 10^3$.	$x^2y \times 10^6$.
Over 0·228	} None	...	...	...	0·210	118 } 200	− 1	− 118	118
					0·209	82	− 2	− 164	328
0·228	2 } 3	17	34	578	0·208	74 } 121	− 3	− 222	666
0·227	1	16	16	256	0·207	47	− 4	− 188	752
0·226	1 } 1	15	15	225	0·206	52 } 103	− 5	− 260	1300
0·225	0	14	...	...	0·205	51	− 6	− 306	1836
0·224	2 } 3	13	26	338	0·204	26 } 51	− 7	− 182	1274
0·223	1	12	12	144	0·203	25	− 8	− 200	1600
0·222	4 } 10	11	44	484	0·202	17 } 27	− 9	− 153	1377
0·221	6	10	60	600	0·201	10	− 10	− 100	1000
0·220	8 } 27	9	72	648	0·200	7 } 11	− 11	− 77	847
0·219	19	8	152	1216	0·199	4	− 12	− 48	576
0·218	26 } 58	7	182	1274	0·198	5 } 8	− 13	− 65	845
0·217	32	6	192	1152	0·197	3	− 14	− 42	588
0·216	58 } 128	5	290	1450	0·196	2 } 2	− 15	− 30	450
0·215	70	4	280	1120	0·195	0	− 16	...	...
0·214	95 } 196	3	285	855	0·194	4 } 4	− 17	− 68	1156
0·213	101	2	202	404	...	0	...	...	...
0·212	106 } 208	1	106	106	under 0·194	} None	...	...	...
0·211	102	...	...	...					
	634		1968	10850		527		− 2223	14713
						634		+ 1968	10850

$$n = \Sigma(y) = 1161$$

$$\Sigma(xy) \times 10 = -255$$
$$\Sigma(xy) \div n = d_0 = -0 \cdot 00022$$

$$\Sigma(x^2y) \times 10^6 = 25563$$

$$\Sigma(x^2y) \div n = 22 \cdot 018 \times 10^{-6}$$
$$\text{Less } (d_0)^2 \quad 0 \cdot 048 \times 10^{-6}$$
$$21 \cdot 970 \times 10^{-6}$$

Origin at 0·211. The 102 occurrences of the ratio 0·211 were taken as evenly distributed between 0·2105 and 0·2115, and similarly for other values.

Arithmetic average = 0·211 − 0·0002 = 0·2108
Median 581st term . . . = 0·2112
Quartiles 290th ,, = 0·2139
871st ,, = 0·2080
Mean of quartiles . . . . = 0·2110
Quartile deviation = r
= "probable error" = ± 0·0030

Standard deviation = σ
$= \sqrt{21 \cdot 970 \times 10^{-6}} = 0 \cdot 0047$
Probable error calculated from σ.
$r' = \frac{2}{3}\sigma = \pm 0 \cdot 0031$.
Standard deviation calculated from quartile deviation.
$\sigma = \frac{3}{2}r = 0 \cdot 0045$.

TABLE II. (*continued*).—*Comparison of Actual and Expected Distribution of Observations Taking the Average* $=0\cdot211$ *and* $\sigma=0\cdot0045$. (*Probable value* $=0\cdot211\pm0\cdot003$.)

Range of Values.	Probability * that Ratio will be within this Range $F(z)$.	Expected Distribution per Cent. (diff. × 100)	Actual Distribution. Total.	Actual Distribution. Per Cent.
$0\cdot211$ to $0\cdot211+3\sigma=0\cdot224$	$F\ (3)=0\cdot499$	0·1	4	0·3
$0\cdot211$,, $0\cdot211+2\sigma=0\cdot220$	$F\ (2)=0\cdot477$	2·2	13	1·1
$0\cdot211$,, $0\cdot211+\sigma=0\cdot215$	$F\ (1)=0\cdot341$	13·6	143	12·3
$0\cdot211$	$F\ (0)=0\cdot0$	34·1	372	32·1
$0\cdot211$,, $0\cdot211-\sigma=0\cdot207$	$F\,(-1)=0\cdot341$	34·1	376	32·5
$0\cdot211$,, $0\cdot211-2\sigma=0\cdot202$	$F\,(-2)=0\cdot477$	13·6	201	17·2
$0\cdot211$,, $0\cdot211-3\sigma=0\cdot198$	$F\,(-3)=0\cdot499$	2·2	38	3·3
		0·1	14	1·2
		100	1161	100

Number of results between $0\cdot210$ *and* $0\cdot220$ *inclusive*—i.e. *between* $0\cdot2095$ *and* $0\cdot2205$.

$$0\cdot2095-0\cdot211=-0\cdot0015=-0\cdot33\sigma$$
$$0\cdot2205-0\cdot211=+0\cdot0095=+2\cdot11\sigma$$

Expected: $\left\{F(-0\cdot33)+F(2\cdot11)\right\}\times100=(0\cdot129+0\cdot483)\times100$
$=61\cdot2$ per cent.

Actual: 735 in 1161 $=63\cdot3$ per cent.

Number of results correct to $\pm$ 2 *per cent.*—i.e. *between* $0\cdot215$ *and* $0\cdot207$ *inclusive.*

2 per cent. of $0\cdot211=0\cdot00422=0\cdot94\sigma$.

Expected: (between $+0\cdot94\sigma$ and $-0\cdot94\sigma$) $=2F(0\cdot94)\times100=200\times0\cdot326$
$=65\cdot2$ per cent.

Actual: 795 in 1161 $=68\cdot4$ per cent.

---

* This is most conveniently obtained from the integral:

$$F(z)=\frac{1}{\sqrt{2\pi}}\int_0^z e^{-\frac{1}{2}z^2}\,.\,dz \quad . \quad . \quad . \quad . \quad . \quad (1)$$

rather than from the usual probability integral:

$$\phi(x)=\frac{2}{\sqrt{\pi}}\int_0^x e^{-x^2}\,.\,dx \quad . \quad . \quad . \quad . \quad . \quad (2)$$

In (1), σ is used as the unit of reduction instead of the usual modulus $c=\sigma\sqrt{2}$.

Thus $F(1)$ = area of probability curve which stands on the base 0 to σ;
while $\phi(1)$ = ,, ,, ,, ,, ,, $-\sigma\sqrt{2}$ to $+\sigma\sqrt{2}$.

Tables of $F(z)$ are given in A. L. Bowley's "Elements of Statistics," 1920, p. 271, but if these are not available tables of the usual probability integral can be used, since $F(z)=\frac{1}{2}\phi(x)$, when $x=\dfrac{z}{\sqrt{2}}$.

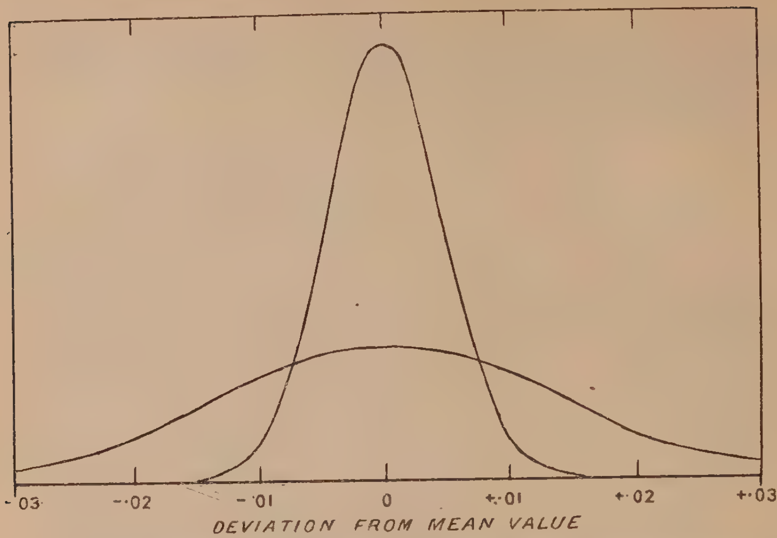

FIG. 3.—Probability Curves, showing Comparative Effect of Probable Errors of $\pm 0 \cdot 003$ and $\pm 0 \cdot 010$ on the Frequency of Occurrence of a given Value of the Ratio.

EXAMINATION OF RESULTS OBTAINED BY OTHER INVESTIGATORS.

Values of some Continental determinations of the ratio of tensile strength (expressed in tons per square inch) and Brinell hardness number (10-millimetre ball and 3000-kilogramme load) are given in the following summary.[2] The method adopted by Grard was to cut a test-bar longitudinally from the material, make hardness tests on the side and on the end (*i.e.* on a longitudinal and a transverse section in the material), the ratio being calculated from the result of the longitudinal tensile test T_L, and each of the two values for Brinell hardness, H_L and H_T. The other investigators mentioned adopted a similar method of calculation, but carried out their hardness tests, not on the actual test-bar, but at adjacent positions. (See table, p. 345.)

Charpy made some tests (quoted by Brinell and Dillner) with a ball of 8 millimetres diameter and a load of 4000 kilogrammes. He obtained a ratio of $0 \cdot 223$ on steels with a hardness below 175, and of $0 \cdot 213$ on steels with a hardness above 175, the hardness

tests being made on the transverse section cut through the enlarged ends of the longitudinal tensile test-pieces.

Some authorities instead of giving ratios prefer to give a tabular statement of Brinell hardness numbers and equivalent

Investigator.	Material.	Average Ratio. $\frac{T_L}{H_L}$	Average Ratio. $\frac{T_L}{H_T}$
1. Brinell.	Rolled Fagersta steels of different carbon content, mainly over 0·5 per cent. carbon	...	0·220
2. Dillner.	Swedish steels, acid and basic, rolled and annealed.		
	Hardness below 175, carbon below 0·5 %	0·230	0·225
	Hardness above 175, carbon above 0·5 %	0·218	0·206
3. Ast.	Steels (22 to 55 tons per square inch); the ratio decreased regularly with increasing tensile strength	0·216 to 0·237	
4. Breuil.	Steels (21 to 48 tons per square inch); the ratio showed no relation to the hardness of the steel	0·211 to 0·239	
5. Grard.	Extra mild steel, hardness < 120	0·229	0·219
	Mild steel annealed, hardness 120 to 160	0·225	0·217
	Medium carbon steels annealed, hardness 160 to 180	0·224	0·214
	Hard steels, annealed	0·222	0·204
	Mild steels, quenched and tempered	0·220	...
	Medium carbon steels, quenched and tempered	0·219	...
	Hard steels, quenched and tempered	0·202	...
6. Révillon.	Silico-manganese steels, hardness 185 to 229	0·247	
7. Döhmer.*	Carbon steels	0·23	
	Nickel and nickel-chromium steels	0·22	

* Figures obtained by various German steelworks.

tensile strength. The table given by Brearley [3] for forged and heat-treated steels embodies the following values of the ratio: 0·230 when the hardness is less than 170, falling to 0·220 when the hardness increases to 180, and then to a constant value 0·218 for all material having a Brinell hardness number exceeding 200. Hanby [4] gives a table which shows a ratio of 0·24 for very soft steels, decreasing to 0·21 for steels of hardness 500, the value being about 0·215 over the range 200 to 400. Sir Robert

Hadfield's table[5] displays a fall in the ratio from over 0·25 for soft steels to about 0·211 for steels with a hardness of 375, above which the ratio again increases slightly. Unwin[6] has expressed the relation by the formula

$$T = 0{\cdot}2H + 6,$$

which is equivalent to

$$\frac{T}{H} = 0{\cdot}2 + \frac{6}{H}$$

that is, the ratio diminishes as the hardness increases, but the constants in this equation give too high a value for the ratio. Abbott[7] has done an immense amount of work on the relation between the tensile strength and Brinell hardness number of nearly 4000 steels. Unfortunately no details are given, except a graph of the results in diagrams of which the ordinates are maximum stresses and the abscissæ Brinell hardness numbers. Through the positions of maximum density, Abbott has drawn a mean straight line, and has thence deduced a series of equations for carbon, nickel, chromium-vanadium, and nickel-chromium steels, all having the form $T = aH - b$, the negative implying that for steels of a given type the ratio $\frac{T}{H}$ increases with increase of hardness. Such an increase (for steels below a hardness of 400) appears to be contrary to the experience of all other investigators. It is, however, impossible, in the absence of more definite data than are conveyed in the small diagrams contained in the paper, to do more than record the fact that Abbott's equations are at variance with general experience in giving far too big a difference in the ratios for soft and for hard steels, and, moreover, in showing a variation in the opposite sense to that generally accepted. Döhmer[2] gives several formulæ used by German steelworks; from his own results he obtains the general formula

$$T = 0{\cdot}218H + 3,$$

but he gives as the formula most representative of the general relation between tensile strength and Brinell hardness number:

$$T = 0{\cdot}22H + 1{\cdot}3.$$

McWilliam and Barnes[8] have published details of 117 tests on nickel, chromium, and vanadium steels. From these they concluded that the ratio of tensile strength to Brinell hardness

number for all the steels examined in all conditions as regards heat treatment was about 0·24. Ninety-one values were quoted as more representative than others, and these selected results give:

	Probable Value of Ratio.
For steels having tensile strengths below 50 tons per square inch	0·239 ± 0·008
" " " above " "	0·237 ± 0·007

All the 117 tests give a probable value of 0·241 ± 0·008.

The average is considerably higher than that obtained by most investigators, and individual results are scattered over a wider range of values; it seems probable that the values are affected by a constant error.

There are many sources which might be explored for information on the tensile-Brinell ratio, quite apart from publications which formally deal with a determination of the ratio. Prominent among these is the Report of the Steel Research Committee of the Institution of Automobile Engineers,(9) in which the necessary data (tensile strength of longitudinal test-pieces and Brinell hardness number of the material of the test-piece) are available. This Report is especially valuable, as it combines the work of a number of investigators, but for that reason also, the deviation of the results from the mean is rather greater than might be expected for determinations made under standard conditions in one testing laboratory. The results given in the Report may be summarised as follows:

Data obtained from the Report of the Steel Research Committee of the Institution of Automobile Engineers, London, 1920.

Tensile tests longitudinal; hardness on longitudinal surface. $\left(\text{Ratio } \frac{T_L}{H_L}\right)$

Alloy Steels (Nickel and Nickel-Chromium).			Carbon Steels.		
Hardness.	No. of Steels.	Probable Value of Ratio.	Hardness.	No. of Steels.	Probable Value of Ratio.
Under 200	109	0·217 ± 0·007	Under 150	35	0·229 ± 0·006
200 to 249	72	0·213 ± 0·006	150 to 174	48	0·222 ± 0·008
250 ,, 299	91	0·215 ± 0·005	175 ,, 199	68	0·220 ± 0·009
300 ,, 349	65	0·218 ± 0·009	200 ,, 249	94	0·216 ± 0·010
350 ,, 399	46	0·220 ± 0·007	250 ,, 299	22	0·212 ± 0·009
400 ,, 449	32	0·222 ± 0·007	...	...	...

A useful set of results referring to 113 heat-treated carbon steels containing carbon 0·5 to 0·6 per cent., and manganese 1·1 to 1·3 per cent., is given by Shepard.[10] Hardness tests were made on flats ground longitudinally on machine-gun barrel steels from which longitudinal tensile test-pieces were afterwards cut. The results, classified according to hardness, give the following values of the ratio $\frac{T_L}{H_L}$:

Carbon Steels, Heat-Treated (Shepard).

Hardness.	No. of Steels.	Probable Value of Ratio.
200 to 249	41	$0{\cdot}212 \pm 0{\cdot}004$
250 ,, 299	60	$0{\cdot}218 \pm 0{\cdot}012$
300 ,, 350	12	$0{\cdot}220 \pm 0{\cdot}005$

Other conveniently collected results are those recorded by Gillett and Mack.[11] They give the results of a number of their own tests, and quote tests carried out by J. Strauss of the American Naval Gun Factory. From those data the following values were calculated ; the Brinell hardness number was given to the nearest 5, but this is not likely to affect the average of a large number of results, or the probable error.

Data obtained from Gillett and Mack's "Molybdenum, Cerium, and Related Alloy Steels."

Hardness on longitudinal surface ; tensile tests, longitudinal and transverse.

Hardness.	Alloy Steels (Gillett and Mack).		Alloy Steels (J. Strauss).	
	No. of Steels.	Probable Value of Ratio.	No. of Steels.	Probable Value of Ratio.
200 to 249	12	$0{\cdot}224 \pm 0{\cdot}015$	...	...
250 ,, 299	31	$0{\cdot}217 \pm 0{\cdot}011$	...	...
300 ,, 349	46	$0{\cdot}214 \pm 0{\cdot}004$	36	$0{\cdot}214 \pm 0{\cdot}004$
350 ,, 399	33	$0{\cdot}219 \pm 0{\cdot}007$	61	$0{\cdot}211 \pm 0{\cdot}004$
400 ,, 449	42	$0{\cdot}222 \pm 0{\cdot}007$	48	$0{\cdot}210 \pm 0{\cdot}004$
450 ,, 550	...	...	70	$0{\cdot}222 \pm 0{\cdot}006$

The above results are based on both longitudinal and transverse tensile tests. The average ratio based on longitudinal tensile

tests $\frac{T_L}{H_L}$ is slightly greater than that based on transverse tensile tests $\frac{T_T}{H_L}$ on the same material, thus:

	For Steels of Hardness between	Average Ratio.	
		$\frac{T_L}{H_L}$	$\frac{T_T}{H_L}$
Gillett and Mack .	200 to 450	0·217	0·213
Strauss . . .	300 ,, 450	0·212	0·209

CONCLUSION.

The ratio of tensile strength to Brinell hardness number is dependent on the hardness of the material and on its yield ratio. Since all steels of the same hardness do not give the same yield ratio, the ratio is to some extent dependent on composition and heat treatment. For a given class of steel the ratio decreases with increase of yield ratio, and also decreases with increase of hardness up to 375 to 450, depending on the composition of the steel. In material of greater hardness it rises again.

Table III. summarises the ratio of tensile strength to Brinell hardness number calculated from data obtained in the Research Department, Woolwich, and from the sources indicated. Values of the ratio deduced from three published tables of Brinell hardness number and corresponding tensile strength are added for comparison.

From this table a close approximation to the correct ratio for any hardness can be obtained, but in practice it is often desirable to make use of a simple factor which can be easily remembered. The values recommended are:

(1) For heat-treated alloy steels, with a Brinell hardness of 250–400 . 0·21

(2) For heat-treated carbon steels and for alloy steels with a Brinell hardness below 250 . . . . 0·215

(3) For medium carbon steels, as rolled, normalised, or annealed . 0·22

(4) Mild steels have not been examined in the Research Department, Woolwich, in sufficient number to make it possible to give a definite ratio, but published work indicates that 0·23 is a suitable value to adopt for these steels as rolled, normalised, or annealed.

These ratios do not apply to severely cold-drawn nor to austenitic steels.

TABLE III.—*Value of the Ratio of Tensile Strength to Brinell Hardness Number.*

Brinell Hardness Number, 10-mm. diam. ball, 3000-kg. load.	Carbon Steels.			Alloy Steels.				From Tables.		
	Research Department, Woolwich.	Institution of Automobile Engineers Research Committee.	Shepard.	Research Department, Woolwich.	Institution of Automobile Engineers Research Committee.	Gillett and Mack.	Strauss.	Hadfield.	Brearley.	Hanby.
150	0·223	0·229	...	...	...	...	...	0·240	0·229	0·228
175	0·218	0·221	...	0·214	0·217	...	...	0·234	0·224	0·230
225	0·215	0·216	0·212	0·211	0·213	0·224	...	0·227	0·220	0·215
275	...	0·212	0·218	0·211	0·215	0·217	...	0·218	0·217	0·217
325	...	...	0·220	0·210	0·218	0·214	0·214	0·212	0·218	0·215
375	...	...	...	0·212	0·220	0·219	0·211	0·211	0·219	0·216
425	...	...	...	0·213	0·222	0·222	0·210	0·216	0·219	0·217
475	...	...	...	...	...	...	0·222	0·225	0·218	0·214

The British Engineering Standards Association [12] suggests for general purposes a ratio 0·22, while the corresponding German Association [13] recommends :

For carbon steels, tensile strength 19 to 63·5 tons per square inch . . 0·23
For alloy steels, tensile strength 41 to 63·5 tons per square inch . . 0·215

Systematic users of Brinell hardness tests are well aware of the differences in the Brinell hardness number determined with reasonable accuracy at points a short distance apart in the same specimen. These differences give a numerical indication of actual variations in properties from point to point and are useful as an indication of the departure from uniformity of a piece of steel, but they are a source of error in determining the ratio of tensile strength to hardness number unless special precautions are taken. Thus, it is rarely that the value of the ratio for a series of steels is known with a probable error of less than $\pm$ 0·003. The existence of this probable error is a further argument for the use of an approximate ratio in round numbers. Until the probable error is reduced, the accuracy with which the

forecast of tensile strength can be made from the Brinell hardness number is but little affected by the use of an approximate rather than the true mean value of the ratio. This is illustrated by the following Tables IV. and V., calculated in the manner indicated in the footnote to Table II., in which actual and calculated results for a series of steels are compared.

TABLE IV.—*Assuming the Ratio is known with a Probable Error (r), the following Figures show the Probability per Cent. that the Tensile Strength calculated from the Mean Value of this Ratio will be Correct to within the Limits indicated.*

Probable Error in Ratio.	Tensile Strength Correct to within—				
	±1 per Cent.	±2 per Cent.	±3 per Cent.	±5 per Cent.	±10 per Cent.
± 0·003	38	67	86	99	100
± 0·005	23	44	62	86	99
± 0·010	12	23	34	54	86

TABLE V.—*Probability per Cent. that the Tensile Strength Deduced from the Brinell Hardness Number by an Approximate Factor is Correct to* ± 2 *per Cent. when the Accuracy with which the True Ratio is known is Expressed by a Probable Error of* (1) ±0·003, (2) ±0·010.

Value of Ratio.	Probable Error ± 0·003.			Probable Error ± 0·010.		
	Factor Used.					
	0·22.	0·215.	0·21.	0·22.	0·215.	0·21.
0·226	36	7	0·5	22	18	13
0·224	51	16	2	22	20	15
0·222	62	28	5	23	21	17
0·220	67	43	11	23	22	19
0·218	62	57	21	23	22	20
0·216	50	65	34	22	22	21
0·214	34	65	50	21	22	22
0·212	20	55	60	19	22	22
0·210	10	41	65	18	21	22
0·208	4	26	60	16	20	22
0·206	1	14	47	14	18	21
0·204	0·4	6	32	12	17	20

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(3) H. Brearley, "The Case-Hardening of Steel," 1921, p. 115.

(4) W. Hanby, "Metals in Aircraft Construction," 1920, p. 22.

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(9) Institution of Automobile Engineers, *Report of Steel Research Committee*, 1920.

(10) W. K. Shepard, *American Machinist*, 1919, vol. l. p. 739.

(11) H. W. Gillett and E. L. Mack, "Molybdenum, Cerium, and Related Alloy Steels" (New York, 1925), pp. 123–129, 187, and 188.

(12) British Engineering Standards Association, *Specification No.* 240, 1926.

(13) Normenausschuss der Deutschen Industrie, *Normenblatt Nr.* 1605.

DISCUSSION.

Professor THOMAS TURNER (Member of Council) said that it was known that there was a general uniform relationship between the tensile strength and the Brinell hardness, but obviously it would vary somewhat according to the characteristics of the material that was being dealt with, and it was impossible to get one ratio that would be equally and generally applicable. He remembered a discussion which occurred at a meeting of the Institute when Mr. Shore was in this country, on the connection between the Shore scleroscope and the Brinell hardness numbers, and Mr. Shore then demonstrated that there was a ratio. Personally he had endeavoured to indicate the ratio some years previously, and has placed the figure as approximately 1 to 6. Mr. Shore showed that the ratio had to be variable according to the material that was being examined, and that a simple number such as he (Professor Turner) had suggested in the first place required modification. Obviously that was the same in connection with the work which the authors were doing. They had given in the paper figures varying only so far as from 0·21 to 0·23, but if they were to turn from substances like mild steel to materials such as non-ferrous metals he was sure they would find that their ratio would be somewhat different. At the same time it was very interesting to have a ratio and to know that it could be used, so long as the same material in the same condition was under investigation.

Mr. J. A. JONES, in reply, thanked Professor Turner for his remarks, and said that the authors realised that the values they had given were only applicable to steels and not to non-ferrous materials. They had pointed out in the paper that the ratios did not apply to severely cold-drawn or to austenitic steels.

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THE EFFECTS OF ARSENIC ON STEEL.*

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Discussion of Previous Work.

Arsenic, occurring in the same column in the periodic table as phosphorus, and having properties in many ways similar, was long considered an element whose presence would be injurious to the physical properties of steel. During the early 'nineties, in fact, specifications for steel were drawn up in which a limit was set on the allowable percentage of phosphorus and arsenic considered together. At that time a considerable amount of work, initiated by Harbord and Tucker and continued and extended by the late Dr. J. E. Stead, was done on steels containing arsenic. The results of those investigations indicated that arsenic did not affect the physical properties of steel to anything like the same extent as phosphorus, and interest in the subject waned. Since the appearance of Stead's work in the Journal of the Institute,[7] little work has been done on the subject, though the sciences of metallurgy and of metallography have advanced remarkably since that time.

From a study of the literature bearing on the effects of arsenic on steel the following more important points seem to be pretty well established :

1. Arsenic present in ores and other materials charged into the blast-furnace will practically all be reduced and enter the pig iron.[3]

2. Arsenic present in pig iron and other materials used in the manufacture of steel will all enter the steel.[3]

3. Arsenic present in steel tends to increase the ultimate strength and decrease the ductility, but these effects are not material until the amount of arsenic present exceeds 1 per cent.[2, 4, 6, 7, 8, 13]

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4. Arsenic up to 1 per cent. does not materially affect the brittleness of steel as measured by bending tests,[6, 7, 11] though Harbord and Tucker [4] fixed the limit at 0·19 per cent.

5. Arsenic in excess of 0·1 per cent. appreciably affects the welding properties of steel.[1, 4, 7, 8]

6. Arsenic up to 4 per cent. does not appear to produce serious red-shortness.[4, 7, 8, 11]

7. Arsenic up to 1·5 per cent. does not affect the results obtained by the ordinary heat treatment processes applied to steel.[4, 6, 7]

8. Arsenic dissolves in iron to form solid solutions.[10, 11, 15] Maximum solubility, 6·8 per cent.[14]

9. Arsenic and iron form compounds which are hard and brittle.[1, 3, 4, 10]

10. Arsenic entering steel by cementation processes ejects carbon from solution in γ-iron.[8, 15]

11. Arsenic does not appear to segregate in steel.[10]

12. Arsenic tends to retard the corrosion of steel.[1, 7, 15]

Reports differ as to the effect of arsenic on the transformation points of iron. Osmond [5] stated that Ar3 was raised and weakened by the presence of arsenic, Ar1 and Ar2 being practically unaffected. Arnold,[6] on the other hand, found that while Ar2 was not affected both Ar1 and Ar3 disappeared.

Present Investigations.

For the purposes of this investigation three sections, 18 in. × 18 in. × 7 in., were cut by means of an oxy-acetylene torch from the ends of blooms of basic open-hearth steel of very nearly the same chemical composition, but differing in arsenic content. For control and comparative purposes a billet 16 in. × 6 in. × 6 in. of the steel, but without arsenic, was also obtained. All samples were made by the same company and by similar methods; the arsenic in the steels was traced to a certain ore used in the blast-furnace burden, no special additions being made during the steel making or pouring. The heat numbers and ladle analyses of these steels are given in Table I.

TABLE I.—*Heat Numbers and Ladle Analyses of Steels used in the Investigations.*

Heat. No.	C. Per Cent.	Mn. Per Cent.	P. Per Cent.	S. Per Cent.	Si. Per Cent.	As. Per Cent.
1571	0·50	0·57	0·012	0·032	0·21	0·198
2065	0·51	0·51	0·015	0·034	0·22	0·363
3664	0·50	0·50	0·043	0·046	0·20	0·457
5399	0·50	0·54	0·014	0·032	0·19	nil

To investigate the problem of arsenic segregation the arsenic steels were sampled by drilling four holes, 1 inch in diameter, 1 inch deep, and equally spaced on a diagonal from one corner to the centre of the billet on the end opposite to that at which the oxy-acetylene cutting had been done. The corner hole was drilled first and numbered 1, and the remaining holes were numbered and drilled in order. The first ½ inch of drillings from each hole was discarded. The results of the analyses of these samples, obtained by a method specially worked out,[16] are shown in Table II.

TABLE II.—*Analyses for Arsenic Segregation.*

Sample No.	Arsenic. Per Cent.	Average Arsenic. Per Cent.
1571–1	0·200	
–2	0·208	0·201
–3	0·205	
–4	0·192	
2065–1	0·233	
–2	0·220	0·222
–3	0·210	
–4	0·225	
3664–1	0·260	
–2	0·215	0·238
–3	0·213	
–4	0·262	

With the exception of No. 1571, the arsenic contents of the billets, set out in the third column of Table II., show no agreement with the arsenic content given by the ladle analyses in Table I.

The manufacturers of the steel reported a tendency for arsenic to segregate, though this phenomenon has not been reported by others. It is probable, however, that arsenic, like phosphorus, does segregate, and that the low results obtained in Table II. are due to the removal of the segregated arsenic by the cropping of the blooms. This assumption is substantiated by the statement of the manufacturers that the opposite ends of the same billet would give varying results.

A comparison of the arsenic content of the steels shown in Tables I. and II. strongly suggests that an equilibrium exists between the arsenic and carbon, which tends to limit the arsenic concentration to about 0·2 per cent. in steels containing 0·5 per cent. carbon. Oberhoffer and Gallaschik [14] have shown that iron can hold up to 6·8 per cent. arsenic in solid solution. A 0·50 per cent. carbon steel has approximately 41 per cent. free ferrite, and, assuming all the arsenic to be present in solid solution in the ferrite, it should be capable of carrying about 2 per cent. of arsenic. With only 0·2 per cent. of arsenic present, it would appear as though the carbon had materially reduced the dissolving power of γ-iron for arsenic. Microscopic examination does not show the presence of an arsenic-rich eutectic similar to the phosphorus-rich eutectic found by Stead to be developed in high-phosphorus, high-carbon steels. A study of the equilibrium relations of the ternary system iron-carbon-arsenic would be necessary for further information on this subject. It has to be assumed for the present that the arsenic originally present in excess of 0·2 per cent. has been completely liquated to the upper part of the ingot during solidification, and was subsequently discarded in the cropping, or has volatilised during the heating and rolling.

Forging.—The blooms were forged to bars of 1 inch square section. The arsenic-bearing steels were first cut longitudinally along the median line by means of an oxy-acetylene torch, forming two billets, each about 16 in. × 8 in. × 7 in. in dimensions. One of each of these billets was forged to the required size, the other being scrapped. During the oxy-acetylene cutting the characteristic white fumes and garlic odour of arsenic were apparent from all the billets.

Examination of the samples previous to forging disclosed the fact that, whilst there were no definite indications of red-shortness

on the surface of the metal, there was a very definite line of weakness, in the form of a crack, through the centre of the original bloom, parallel to the 18 in. × 18 in. face exposed by the oxy-acetylene cutting. This crack, which was practically continuous round the bloom, gave considerable trouble in the preliminary forging operations, particularly on metal No. 2065.

The procedure of forging was the same for all the samples. The metal was brought to the required forging temperature in an oil-fired furnace, and the bloom forged under a 2000-lb. hammer to a bar about 5 inches square, which was cut into pieces 7 to 9 inches long. Each of these small pieces was reheated in a smaller oil-fired furnace and about half of it forged to $1\frac{1}{2}$ inch square section under a 1500-lb. hammer, and immediately finished to a 1 inch square section under an 800-lb. hammer. The remaining portion of the piece was reinserted in the furnace, brought to forging temperature, and completed in the same manner.

Details of the observations made during the forging of each sample are given below. It is to be noted that no temperature measurements were taken, and reference to temperature differences are purely the relative judgment of the observer.

Bloom No. 1571.—Under the initial hammer blows on this sample the centre crack already noted opened conspicuously on the end of the bloom, and a cross crack developed with the plane of fracture perpendicular to the main plane of weakness. This cracked end was cut off and forged separately, the remainder of the sample being returned to the furnace. On continued forging the cracks appeared to close and weld satisfactorily. The remainder of the metal, brought from the furnace at a slightly higher temperature, worked satisfactorily under the initial forging operations, and none of the smaller pieces gave any trouble in the finishing operations under the smaller hammers.

Bloom No. 2065.—The forging of this billet was begun at an appreciably lower temperature than that of bloom No. 1571. The bloom opened badly both vertically and horizontally in the direction of the original rolling. A piece was cut off the end and split along these open cracks. The remainder of the bloom was returned to the furnace and brought to a higher temperature. On continuing the forging the cracks already opened did not close well, and the final small pieces for the succeeding forging operations

had to be obtained by slicing the bloom along these cracks. In the final forging operations these cut pieces were kept at a good temperature and gave little trouble, although there was at all times a tendency for the extreme ends of the bars to open slightly.

Bloom No. 3664.—The preliminary forging operations on this sample were done at a distinctly higher temperature than the others. Longitudinal cracks opened somewhat in both planes parallel to the forging operations. The majority of these cracks closed satisfactorily under continued working, but some persisted throughout the forging with the 2000-lb. hammer. No further difficulties were encountered in completing the forging to the 1 inch square bars under the smaller hammers.

Bloom No. 5399.—This bloom, containing no arsenic, gave no difficulty in the forging operations.

Examination of the forged bars revealed the presence of surface cracks or seams in the arsenic-bearing steels. These cracks appeared as long but discontinuous fissures running longitudinally down the centre of practically all the bars, and appeared to be concentrated near the centre of each surface. The seams were about as numerous in the bars from bloom No. 1571 as in those from bloom No. 3664. No such seams were noted in the bars from the plain carbon steel. This seaming under forging was a distinct characteristic of the arsenic-bearing metal, and indicates that the presence of the arsenic tended to produce red-shortness in the metal. This tendency was, in part at least, overcome by using slightly higher temperatures for forging. Both forge-men stated that the metal appeared to stand a high heat well, and that it appeared to be somewhat "harder" and "tougher" than ordinary metal of the same general composition.

During the forging operations the characteristic garlic odour of arsenic was just as apparent from the metal of bloom No. 1571 as from that of bloom No. 3664, and there was apparently an appreciable loss of arsenic during those operations. Chemical analyses made on turnings obtained from the finishing cut in turning up the tensile test-bars are shown in Table III. These results check the ladle analyses for all the elements except arsenic. Phosphorus in No. 3664 is a little high, and probably some arsenic is reported here, but the arsenic figures check neither the ladle analyses nor the analyses of the rolled metal shown in the third

column of Table II. For purposes of comparison and discussion the results of these various determinations are brought together in Table IV., which shows quite clearly that, while the loss of

TABLE III.—*Chemical Analyses of Forged Metal.*

Heat No.	C. Per Cent.	Mn. Per Cent.	P. Per Cent.	S. Per Cent.	Si. Per Cent.	As. Per Cent.
1571	0·49	0·54	0·010	0·032	0·20	0·179
2065	0·50	0·51	0·013	0·030	0·21	0·206
3664	0·50	0·49	0·050	0·040	0·22	0·217
5399	0·51	0·54	0·012	0·034	0·20	nil

arsenic during forging has been a proportional loss, that due to casting is certainly not, a fact which bears out the argument already put forward that during solidification of the original ingot there must have been a considerable segregation of arsenic towards

TABLE IV.—*Comparison of Results of Determinations for Arsenic.*

Heat No.	Table I. (Ladle). Per Cent. As.	Table II. (Blooms). Per Cent. As.	Table III. (Forged). Per Cent. As.	Diff. I.–II. Per Cent.	Diff. II.–III. Per Cent.
1571	0·198	0·201	0·179	0·0	10·0
2065	0·363	0·222	0·206	38·8	7·2
3664	0·457	0·238	0·217	47·9	8·8

the upper portion of the ingot which was afterwards cropped off and discarded.

Critical Point Determinations.—Previous investigators [5, 6] had held conflicting opinions on the question of the effect of arsenic on the transformation points.

The transformation points of the steels used in this research were determined by means of a Leeds and Northrup manually operated autographic transformation point apparatus. The averages of three separate determinations of each point are shown in Table V., and they indicate that 0·22 per cent. of arsenic has no appreciable effect on either the position of the transformation points of a 0·50 per cent. carbon steel or the intensity of the

transformations, as shown by the size of the "loop" on the curves obtained. The very slight rise in the position of all the points is probably no greater than the minimum error of the apparatus.

TABLE V.—*Transformation Points of Arsenic Steels.*

Steel No. . . . . Arsenic content (per cent.)	5399 0·00	1571 0·18	3664 0·22
Ac1 (deg. C.)	739	742	744
Ar2 (,,)	716	716	718
Ar1 (,,)	688	690	692

Heat Treatment.—As there was no great difference in the arsenic contents of steels Nos. 2065 and 3664 after forging, it was decided to limit the heat treatment and mechanical tests to metal from Nos. 1571, 3664, and 5399.

Heat treatment was carried out in a multiple unit electric muffle furnace; the temperature was controlled by a chromel-alumel thermocouple and Leeds and Northrup potentiometer indicator with manually operated cold junction. The thermocouple was standardised against the melting points of tin, lead, zinc, aluminium, and silver.

Samples of each metal, in duplicate, were subjected to the following heat treatments:

Normalised at 800° C.
Annealed at 800° C.
Quenched from 800° C., drawn at 350° C.
,, ,, 800° C., ,, 500° C.
,, ,, 800° C., ,, 650° C.

To ensure uniformity the samples of each metal were subjected to the same heat treatment at the same time. For preliminary heating to 800° C. they were packed in cast-iron chips in an annealing box, the cover luted tight with fireclay and the box placed in the cold furnace; the temperature was then raised slowly and uniformly at a rate which required about three hours to bring the whole to a temperature of 800° C. to 810° C., which was held for thirty-five minutes. For normalising, the box was removed from the furnace, broken open, and the samples stood on end on an asbestos board to cool. For annealing, the box was

allowed to cool within the furnace, which required ten hours to drop to a temperature of 150° C. For quenching, the box was removed from the furnace, broken open, and the samples quenched in a large bath of water at 75° F. (24° C.).

For drawing, the same furnace was brought to the required temperature, the samples stood on end on an asbestos board separated from the floor by an air space, and so arranged that their centres were approximately in the same horizontal plane as the fire end of the thermocouple. The furnace was brought back to temperature and held there for thirty-five minutes; oxidation of the surfaces of the metal was prevented by placing sufficient charcoal in the furnace to last throughout the duration of the heating. The samples were cooled from the drawing temperature by quenching in water.

Mechanical Tests.—Standard A.S.T.M. tensile tests were carried out in an Olsen 60,000 lb. testing machine, equipped with automatic recording device, on 2-inch gauge length test-bars with threaded ends. Yield point was obtained by the drop of the beam.

Hardness tests were carried out on pieces cut from the ends of the test-bars after fracture, with a 10-millimetre ball and 3000-kilogramme load applied for thirty seconds. The results of Rockwell hardness tests are "B" scale readings for 100-kilogramme load and $\frac{1}{16}$-inch steel ball.

Charpy impact tests were carried out on standard Charpy impact specimens, 0·394 in. × 0·394 in. × 2·165 in., with centre notch 0·039 inch wide and 0·197 inch deep.

The results of the mechanical tests are given in Table VI. They do not show any very marked effect due to the presence of the arsenic, except in the case of the Charpy impact values. There is an increase in strength varying from 2 to 7 per cent. with an average of about 4 per cent., and a corresponding decrease in ductility. Increase in hardness as shown by the Brinell and Rockwell tests is not material.

The possible effects of arsenic upon ductility are of particular importance in view of the rather pronounced effects of the similar element phosphorus upon this property. The table shows that the decrease in reduction in area for the various heat treatments averages about 12 per cent., while the decrease in elongation

averages about 17 per cent. These results are somewhat greater than would be expected to accompany the comparatively slight

TABLE VI.—*Results of Mechanical Tests of Arsenical Steel.*

Steel No.	As. Per Cent.	C. Per Cent.	Yield Point. Lbs. per Sq. In.	Tensile Strength. Lbs. per Sq. In.	Reduction in Area. Per Cent.	Elongation on 2 Inches. Per Cent.	Brinell Hardness No.	Rockwell Hardness No.	Charpy Values. Ft.-lbs.
				Heat Treatment. Normalised at 800° C.					
5399	0·00	0·51	62,000	95,400	49·6	30·0	201	89	13·8
1571	0·18	0·49	60,700	99,300	44·9	24·0	207	91	9·0
3664	0·22	0·50	65,400	102,500	44·1	22·5	207	92	10·5
				Heat Treatment. Annealed at 800° C.					
5399	0·00	0·51	47,300	81,900	50·9	33·0	149	85	9·5
1571	0·18	0·49	45,900	84,200	45·0	30·3	163	86	4·3
3664	0·22	0·50	47,100	88,500	43·3	28·0	179	89	3·0
				Heat Treatment. Quenched from 800° C., Drawn at 350° C.					
5399	0·00	0·51	153,000	153,200	16·3	3·5	285	106	10·7
1571	0·18	0·49	...	148,500	17·7	4·0	311	109	3·5
3664	0·22	0·50	...	157,300	9·0	3·5	331	111	2·0
				Heat Treatment. Quenched from 800° C., Drawn at 500° C.					
5399	0·00	0·51	131,000	147,900	49·9	13·5	302	107	22·7
1571	0·18	0·49	141,000	153,000	46·3	13·0	311	108	17·7
3664	0·22	0·50	135,200	152,000	39·9	11·5	311	108	12·7
				Heat Treatment. Quenched from 800° C., Drawn at 650° C.					
5399	0·00	0·51	58,600	94,800	58·3	26·0	197	93	34·3
1571	0·18	0·49	51,000	94,800	49·2	26·0	197	92	28·2
3664	0·22	0·50	61,300	102,700	53·1	22·0	194	95	24·3

increase in strength. The effects of arsenic on ductility, as measured by these tests, however, is not great.

The results of the tensile tests confirm the findings of other investigators; Stead [7] showed that arsenic in amounts up to 1·0 per cent. had only a slight effect on the physical properties, and McKinney's results [13] showed that 0·3 per cent. of arsenic gave no appreciable effect.

Table VI. shows that the presence of arsenic has materially lowered the Charpy impact values. In the normalised and fully drawn metal the impact values for the steels with arsenic approach reasonably close to the values obtained for the metal without arsenic. In the normalised metals these values are 65 and

80 per cent. of the value for the metal without arsenic, and in the fully drawn samples they are 82 and 71 per cent. respectively. At the extremes of heat treatment, in the softest and hardest conditions, the impact values show the maximum differences. For the annealed metals the values for Nos. 1571 and 3664 are 45 and 32 per cent. of the value obtained for No. 5399. In the metals drawn at 350° C. the impact values for Nos. 1571 and 3664 are respectively only 33 and 19 per cent. of the value for No. 5399. Thus arsenic has its maximum effect when the metal is in the hardened condition, and its least effect when the metal is fully drawn.

The results given in Table VI. show that arsenic has an undesirable effect on the shock-resisting properties of steel as shown by Charpy impact tests, and it is important to note that this defect of the arsenic-bearing metal has not been brought out by the ordinary tensile tests. The only hint is given by the decrease in ductility as measured by the decrease in elongation and reduction in area percentages, which latter have been shown to be slightly greater than would be expected to accompany the very slight increase in strength due to the presence of the arsenic. Table VI. gives further evidence of the fact, brought out by Thomas,(12) that measurements of ductility, as shown by reduction in area and by elongation, are the best criteria obtainable from the ordinary tensile tests for a judgment of the shock-resisting properties of a metal.

Case-Hardening.—The effect of arsenic in steel on the penetration of carbon during case-carburising processes has not been reported upon. To determine this effect a sample of steel No. 5399 and one of steel No. 3664 were packed in a carburising compound in an annealing box and subjected to a temperature of 930° C. in a gas-fired furnace for five hours and allowed to cool with the furnace. The specimens were cut in half and examined for carbon penetration. The depth of penetration of the carbon was practically the same for both metals; the grain-size of the core of No. 3664 appeared to be slightly coarser than that of No. 5399, but the grains were more uniformly sized.

From this experiment it would appear as though the presence of 0·22 per cent. of arsenic in a 0·50 per cent. carbon steel has no appreciable effect on the case-hardening properties of the metal.

Welding Tests.—Previous investigators have reported that the presence of arsenic in steel makes welding more difficult.

Mr. B. Sheppard, Instructor in the Forging Laboratories, Massachusetts Institute of Technology, kindly undertook to make some welding tests on the steels under examination. He reported that the metal would not weld when using the ordinary borax flux, but that he had no difficulty in making good welds with the aid of a special welding compound (Climax). The metal stood the heat satisfactorily, and when once knit bonded well.

The 1 inch square welded bars were allowed to cool in air without quenching, and they gave the following tensile test results:

Steel No.	1571	3664
Arsenic content (per cent.)	0·18	0·22
Tensile strength (lbs. per square inch)	82,500	90,600

These results compare very favourably with the tensile strength of the same metals as given in Table VI. Arsenic does not appear to hinder the welding of such metal when a suitable welding compound is used.

Corrosion Tests.—The effect of arsenic on the corrosion of the steels under examination was studied by immersing samples of the metals in ordinary tap water for about half an hour every three or four hours, and allowing them to dry between immersions. It was believed that this would give a close approximation to ordinary atmospheric corrosion conditions without unduly prolonging the tests.

The samples, consisting of thin pieces cut from the 1 inch square bars, were, previous to the experiments, subjected to the periodic immersions for a period of twenty-eight days; the rust coatings so produced were carefully removed by the aid of $N/10$ hydrochloric acid and fine steel wool, leaving surfaces upon which a minimum amount of cold-working had been done. The samples so prepared were carefully weighed, their surface area measured, and their density determined. They were then subjected to the periodic immersions for periods of three, six, and nine days. At the end of each period they were cleaned from rust in the same manner as before, dried and weighed, and their losses of weight recorded.

If w represents the loss in weight in grammes, s the surface

area in square centimetres, and d the density, then P, the depth of penetration in centimetres, is expressed by the equation :

$$P = \frac{w}{d \times s}$$

If p represents the period of exposure in days, then R, the rate of penetration in centimetres per year, is shown by the equation :

$$R = P \times \frac{365}{p} \times K \text{ (constant).}$$

The results of the corrosion tests are shown in Table VII.

TABLE VII.—*Corrosion of Arsenic Steel.*

Steel No.	s. Sq. Cm.	d.	p. Days.	w. Grm.	$P \times 10^4$. Cm.	$R \times 10^2$. Cm./yr.
5399	16·2	7·85	3	0·022	1·7	2·1
1571	16·3	7·87	3	0·016	1·2	1·5
3664	17·5	7·85	3	0·026	1·9	2·3
5399	16·2	7·85	6	0·057	4·4	2·7
1571	16·3	7·87	6	0·054	4·2	2·6
3664	17·5	7·85	6	0·062	4·5	2·7
5399	16·2	7·85	9	0·094	7·4	3·0
1571	16·3	7·87	9	0·087	6·8	2·8
3664	17·5	7·85	9	0·106	7·7	3·1

From Table VII. it is evident that R is constant well within the limits of error of the experiments, and that the presence of 0·2 per cent. of arsenic has had no effect in either retarding or increasing the rate of corrosion of a 0·50 per cent. carbon steel.

Microstructure.—Specimens for microscopic examination were cut from the ends of the tensile test-bars after fracture. Specimens of hot-worked (forged) metal were obtained from the forged bars. Both transverse and longitudinal sections were examined.

The grain-size of the hot-worked, normalised, and annealed specimens of the arsenic-bearing metals was appreciably coarser, and a greater proportion of laminated pearlite was present than appeared in the specimen of the plain carbon steel. The very coarse grain-size of the hot-worked metal of No. 3664, due probably to a higher finishing temperature of forging, is shown in Fig. 10

(Plate XLVI.). The structures of the fully annealed specimens were practically identical, though the plain carbon steel appeared to show somewhat less free ferrite. Greater quantities or greater coarseness of excess ferrite were apparent in the quenched and drawn specimens of the arsenic-bearing metals Nos. 1571 and 3664 than in the plain carbon steel. The structure of No. 5399 drawn at 350° C. was troostitic; that of Nos. 1571 and 3664 was troosto-sorbitic, and excess ferrite was abundant. The structure of all the metals when drawn at 500° C. was essentially sorbitic, though there again ferrite appeared to be more abundant and less evenly distributed in the structures of Nos. 1571 and 3664. No. 5399, drawn at 650° C., had the typical development of sorbite with excess ferrite well disseminated. A similar structure was found in the arsenic-bearing metals, though again ferrite appeared to have segregated to larger masses. The network structure of No. 1571, shown in Fig. 11, suggests that this specimen was subjected to a temperature which slightly exceeded the Ac1 point, with a consequent development of some pearlite and the ejection of the ferrite to the boundaries.

Plate XLV., Figs. 1–9, illustrates the structures obtained in the examination of the longitudinal sections of the metals, and in these one characteristic stands out prominently. In all the specimens of the arsenic-bearing metals there is shown a distinct banded or "ghost-line" structure. It is as well, if not better, developed in the metal after quenching and drawing at 650° C. than in the hot-worked specimens. Prolonged heating at a high temperature, followed by slow cooling, failed to remove this banded structure. A specimen of each of the metals was subjected to a temperature of 1000° C. for three hours and allowed to cool in the furnace, but even this drastic treatment failed to remove the banding. Except for these bands, the structures in the longitudinal sections were practically identical with those of the transverse sections.

Generally speaking, the structures of the arsenic steels exhibited a greater coarseness of grain-size and a greater separation of ferrite. This might possibly have been due to slight variations in the temperature conditions of the heat treatments, particularly in the drawing operations. These characteristics were, however, equally developed in the normalised and annealed specimens, and, as previously noted, the test-bars for each heat treatment were

No. [illegible] As. 0·00 per cent. No. 1571. As. 0·18 per cent. No. 3664. As. 0·22 per cent.

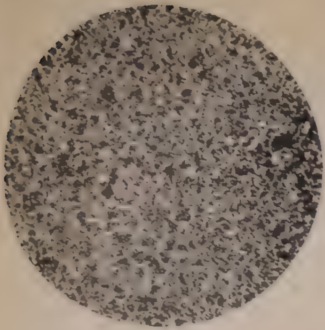


FIG. 1.

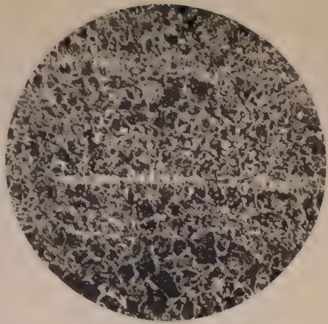


FIG. 2.

FIG. 3.

Longitudinal section; normalised at 800°C. Etched with nitric acid. ×100. (Reduced to $\frac{4}{5}$).

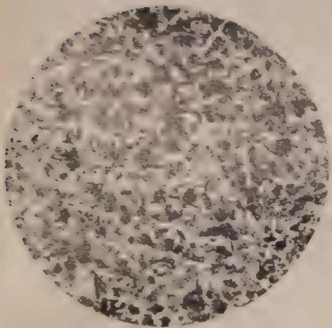


FIG. 4.

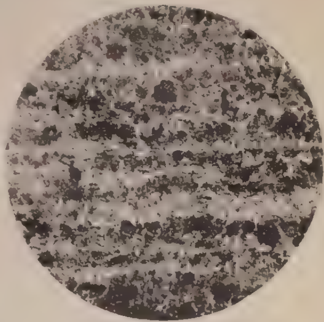


FIG. 5.

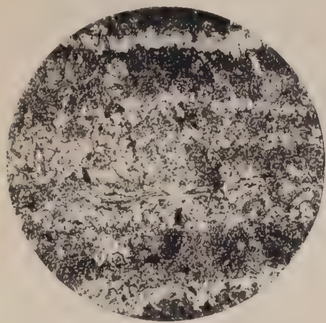
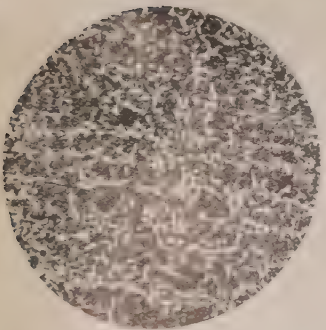


FIG. 6.

Longitudinal section: annealed at 800°C. Etched with nitric acid. ×100. (Reduced to $\frac{4}{5}$).



[illegible] 7.

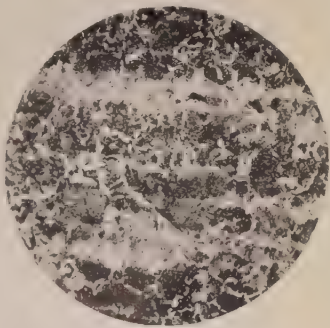


FIG. 8.

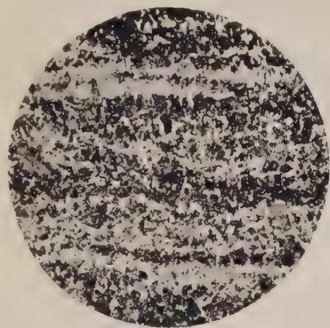
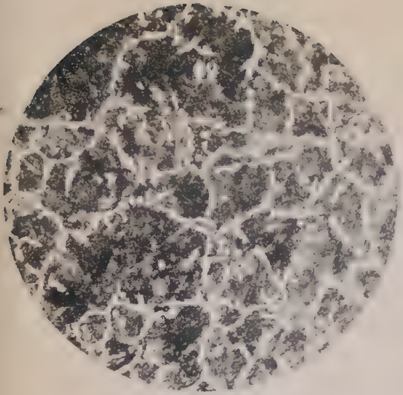


FIG. 9.

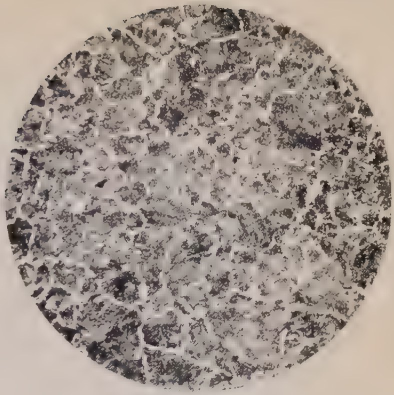
[illegible] quenched from 800°C. drawn at 650°C. Etched with nitric acid. ×100. (Reduced to $\frac{4}{5}$).

[To face p. 368



No. 3664. As. 0·22 per cent.

FIG. 10.—Transverse section. Hot worked. Etched with nitric acid. ×100. (Reduced to ⅘).



No. 1571. As. 0·18 per cent.

FIG. 11.—Transverse section. Quenched from 800°C. drawn at 650°C. Etched with nitric acid. ×100. (Reduced to ⅘)

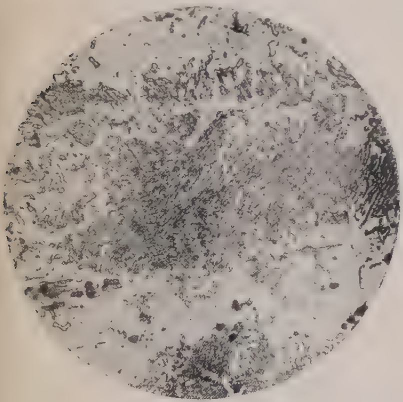


FIG. 12.—×500. (Reduced to ⅘).

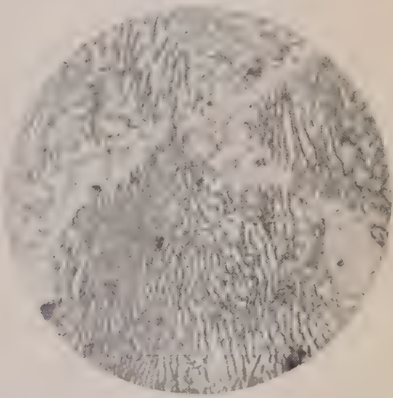


FIG. 13. ×1000. (Reduced to ⅘)

No. 3664. Annealed at 800°C.

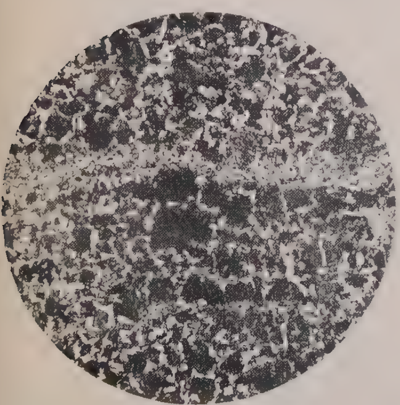


FIG. 14—Longitudinal section No. 3664. Normalised at 800°C. Etched with nitric acid. ×150. (Reduced to ⅘)

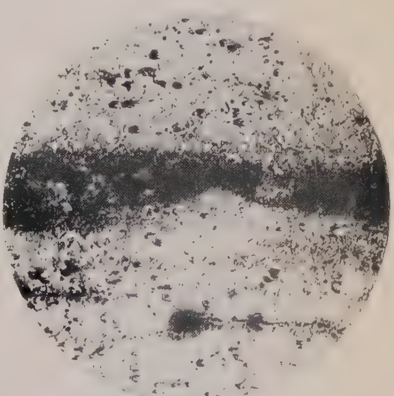


FIG. 15.—Same field as Fig. 14. Etched with Iodine. ×150. (Reduced to ⅘).

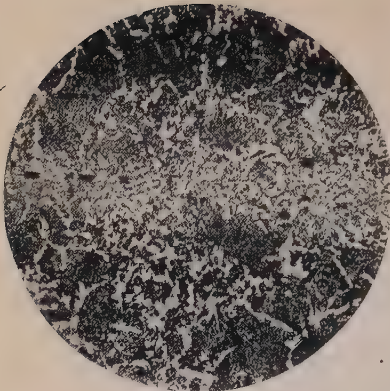


FIG. 16.—Longitudinal section No. 3664. Quenched from 800°C., drawn at 350°C. Etched with nitric acid. ×150. (Reduced to $\frac{4}{5}$).

FIG. 17—Same field as Fig. 16. Etched with iodine. ×150. (Reduced to $\frac{4}{5}$).

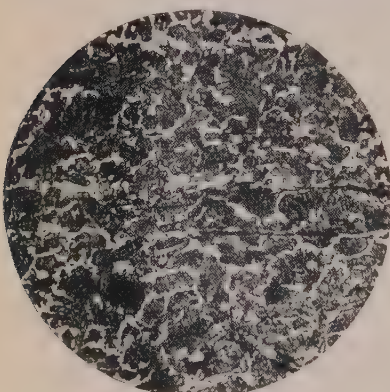


FIG. 18.—Longitudinal section No. 3664. Hot worked. Etched with nitric acid. ×150. (Reduced to $\frac{4}{5}$).

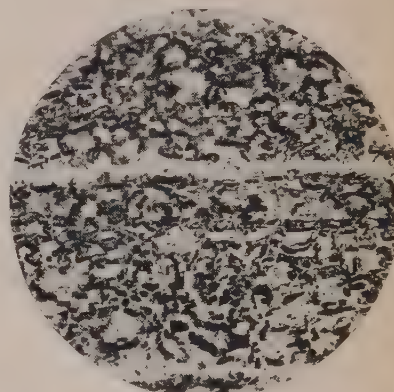


FIG. 19—Same field as Fig. 18. Etched with Le Chatelier & Dupuy's reagent. ×150. (Reduced to $\frac{4}{5}$).

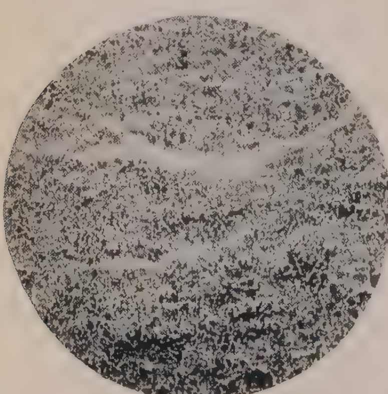


FIG. 20.—Cross section No. 3664. Hot worked. Etched with nitric acid. ×75. (Reduced to $\frac{4}{5}$).

FIG. 21.—Same field as Fig. 20. Etched with Le Chatelier & Dupuy's reagent. ×75. (Reduced to $\frac{4}{5}$).

subjected to the same treatment in the same annealing box at the same time.

The bands or ghost lines shown in the longitudinal sections, consisting of free or excess ferrite, occurred often, though not always, about stringers of slag or other non-metallic inclusions in the metal. Fig. 2 (Plate XLV.) shows the banding without the presence of slag inclusions, and the broad band of ferrite in Fig. 5 shows small quantities of pearlite disseminated through the essentially ferrite area. Hindley [15] showed that arsenic tends to eject carbon from solution in γ-iron, and this fact suggests the probability that the arsenic contained in the metal should be associated with these carbonless, or at least low carbon, areas.

That the ferrite bands do contain arsenic is proved by the use of etching reagents other than nitric acid. Fig. 14 (Plate XLVI.) shows the banded structure in normalised metal of No. 3664 (0·22 per cent. arsenic) when etched with nitric acid. Fig. 15 shows the same field etched with a 10 per cent. solution of tincture of iodine, which has coloured the banded ferrite area black; the black band overruns the adjacent pearlite-sorbite areas. Apparently the arsenic is not altogether segregated to the white ferrite bands, but is also present in the adjacent pearlite-ferrite. Similarly, Fig. 16 (Plate XLVII.), etched with nitric acid, shows a banding of a ferrite-rich area bounded by sorbite or troosto-sorbite areas, these in turn being bounded by areas of troostite. In Fig. 17 the iodine has etched the ferrite and the sorbite areas, but has not touched the troostite. The iodine etch has been lightly rubbed off to bring out the boundaries of the etched areas a little more clearly.

Etching with Le Chatelier and Dupuy's reagent gives similar results. Fig. 18 (Plate XLVII.), a longitudinal section of No. 3664 etched with nitric acid, shows a tendency towards the banded structure. The same field etched with Le Chatelier and Dupuy's reagent, shown in Fig. 19, exhibits a strong banding coinciding with the banding of Fig. 18 and covering both ferrite and pearlite.

Careful differential nitric acid etching of a cross-section of a specimen of hot-worked (forged) metal from No. 3664 developed a series of lighter etched areas covering both pearlite and ferrite (Fig. 20, Plate XLVII.). The same area is brought out in full contrast by etching with Le Chatelier and Dupuy's reagent, as shown

in Fig. 21. This would appear to be evidence of arsenic segregation other than in the bands showing up so conspicuously in the longitudinal sections. Fig. 20 also indicates that the arsenic-rich areas are slightly more resistant to the corroding action of the acid.

The results of the microscopic examination with the aid of various etching reagents point to the fact that arsenic does segregate in steel, in the form, generally, of a banded structure, similar to that developed by phosphorus. It has been shown that the presence of 0·50 per cent. of carbon appears to reduce the solubility of arsenic in γ-iron to a figure in the neighbourhood of 0·20 per cent.; with arsenic originally present in excess of this figure, the excess may be ejected to the upper portions of the solidifying ingot. Stead [9] has shown that, in the presence of carbon, phosphorus is thrown out of solution in γ-iron, and occurs, in part at least, segregated as an iron-iron phosphide eutectic, and the presence of this eutectic is largely responsible for the brittleness of high-phosphorus, high-carbon steels. These two phenomena are very similar, and it was expected that some of the excess arsenic would likewise be found in the solid metal as a eutectic. If present at all, this eutectic would be looked for in the vicinity of the high-arsenic ferrite bands. A close examination of the banded structures at high magnifications failed to reveal the presence of any such eutectic. A typical pearlite-ferrite structure of the 0·22 per cent. arsenic steel, No. 3664, when annealed at 800° C., is shown at 500 magnifications in Fig. 12 (Plate XLVI.), and at 1000 magnifications in Fig. 13. The structure shown is normal pearlite-ferrite, with the pearlite cementite partially spheroidised, due to slow cooling from the annealing temperature. There is here no evidence of a eutectic structure other than that of the pearlite, the absence of which clearly accounts for the comparatively slight effects of arsenic on the physical properties of the steel.

If arsenic and carbon cannot exist in solution together in γ-iron, any arsenic remaining in the metal after solidification would tend to segregate to places low in carbon, and on cooling through the critical range this arsenic-rich γ-iron would presumably break down into arsenic-rich ferrite and pearlite, with the pearlite ferrite of this region richer in arsenic than the major portion of the metal. The microscopic examination has shown

that the pearlite adjacent to the arsenic-bearing ferrite also carries arsenic. Arsenic is thus seen to occur in the metal in solid solution in free ferrite and in the adjacent pearlite ferrite.

The following conclusions may be drawn from this discussion of the microstructure of the steels examined :

1. Arsenic segregates, producing, in general, a banded structure, which persists throughout all heat treatments applied.

2. The persistence of the banded structure gives evidence that arsenic does not diffuse in γ solid solution, and tends to confirm Hindley's statement that arsenic and carbon cannot exist together in solution in γ-iron.

3. Arsenic occurs in the steel only as a solid solution of arsenic in iron. This solid solution occurs partly as free ferrite and partly as pearlite ferrite.

4. There is no evidence of a brittle eutectic of iron-iron arsenide similar to the iron-iron phosphide eutectic found in high-phosphorus steel.

5. The absence of this eutectic probably accounts for the comparatively slight effects of arsenic, as shown by tensile tests.

Summary and Conclusions.

Chemical analyses showed that a considerable loss of arsenic occurred between the casting of the steels and the completion of hot-working. Part of this is accounted for by volatilisation during working, but this would cause a proportional diminution of the arsenic content, whereas the total loss is emphatically not so. This has been taken as evidence of pronounced segregation of the arsenic, or of its liquation in the form of a eutectiferous liquid, to the upper portion of the solidifying ingot. Microscopic examination failed to reveal the presence of any of this eutectic in the forged metal, although it would be reasonable to suppose that, if such separation had taken place, some of the liquid would have been mechanically entangled in the growing dendrites and would appear in the forged metal. Hindley, however, has shown that, at temperatures above 800° C., arsenic diffuses from the eutectic in contact with steel into the adjoining metal with the formation of an iron-arsenic solid solution, and the carbon present in the

adjoining γ-iron is forced out of solution as cementite and enriches the γ solid solution beyond. Under these conditions the tendency would be for any eutectic trapped in the steel to disappear, and the arsenic would be left in solution in a low-carbon, arsenic-rich γ-iron, which would be interdendritic or isolated, and as a result of rolling or forging would appear in the cold metal as stringers or bands. The double solubility of arsenic and carbon in γ-iron being low, there would be no tendency for the arsenic to diffuse far from its original position, and the banded structure would persist throughout any heat treatment. This was found to be the case.

It should be remarked that the two blooms which lost arsenic, Nos. 2065 and 3664, both showed a slightly greater arsenic concentration at the outside and centre than elsewhere. The present investigations indicate that 0·50 per cent. of carbon reduces the solid solubility of arsenic to about 0·20 per cent.

Effect of Arsenic on Physical Properties.—During forging, the arsenic-bearing steels all seamed badly, indicating that arsenic tends to induce red-shortness. They reacted, however, to the heat treatment applied quite as readily as the same steel without arsenic.

In the mechanical tests on the heat-treated steels arsenic showed a tendency to increase the tensile strength with an increase in hardness and a decrease in ductility. In the normalised metals the strength increased to the order of about 150 to 250 lbs. per square inch for each 0·01 per cent. arsenic, which was accompanied by a normal decrease in ductility and increase in hardness. Similar remarks apply to the other heat treatments, although there are greater variations in the ductility values of the hardened metals than would perhaps be expected. In these respects the effect of arsenic resembles that of phosphorus, but is much less marked.

The presence of arsenic had an appreciable effect on the shock-resisting properties of the metal as measured by Charpy impact tests. Here, as in ductility, the maximum effects were shown in the hardened metal. Brittleness, as measured by this test, was also increased by the presence of arsenic, though to a less degree than would have occurred with an equal amount of phosphorus.

From the single experiment on the case-hardening properties of the steels, 0·20 per cent. of arsenic did not appear to have any

appreciable effect, which is contrary to what might have been expected. Hindley showed that arsenic ejects carbon from solution in γ-iron, and from this it would be logical to suppose that the presence of arsenic would retard the rate of penetration of the carbon into steels during case-hardening processes.

Arsenic up to 0·2 per cent. does not interfere with the welding of a 0·5 per cent. carbon steel, nor has it any appreciable effect on the thermal critical points. There appeared to be a slight rise in the occurrence of all the points, and this might be more pronounced when greater quantities of arsenic were present, but there was no indication that the intensity of the transformations was in any way affected.

The presence of arsenic did not affect the rate of corrosion of the steels.

From the discussion of the previous work and the results of the present investigations it is apparent that, while the effects of arsenic are in many ways similar to those of phosphorus, they do not make their appearance until the amount of arsenic present greatly exceeds the maximum allowable amount of phosphorus.

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Iron and Steel Institute

THE SPECIFIC RESISTANCE AND THERMO-ELECTROMOTIVE POTENTIAL OF SOME STEELS DIFFERING ONLY IN CARBON CONTENT.[1]

By E. D. CAMPBELL [2] and H. W. MOHR (Ann Arbor, Michigan).

The solution theory has been quite generally accepted by metallurgists and chemists for more than thirty years, and has formed the background for many researches having for their object the correlation of the chemical constitution and physical properties of steel, especially electrical, thermal, thermo-electric and magnetic properties, as well as the mechanical properties, which latter, however, are not infrequently more dependent on the physical structure as influenced by mechanical work, and so forth, than on the chemical constitution.

Of all the elements usually associated with iron, carbon stands in a class by itself as regards the extent to which it enables the metallurgist to control those physical properties which give steel the important position it holds in modern civilisation. In pure iron-carbon alloys, the carbon is combined with part of the iron in the form of carbides, which may be either in solution or more or less precipitated from the main part of the iron, which is the solvent metal. When a second metallic element is present, it will usually be found to exist partly in the solvent iron, or as a constituent of the carbides or other solutes present, such as silicides, phosphides, sulphides, &c. In order to obtain reliable information concerning the influence of metallic elements other than iron on the specific resistance and thermo-electromotive potential of steel, it is first necessary to have data on these properties on as pure iron-carbon alloys as possible, and then obtain data on samples of

[1] Received June 24, 1925.

[2] [It was with deep regret that the announcement of the death of Professor E. D. Campbell was received by the Council shortly after the Autumn Meeting in September 1925. This paper is probably the last contribution of this eminent American metallurgist to the literature of science.—Editor.]

corresponding carbon content, but in which the other metallic elements are present in constant amounts.

In a comprehensive study of the correlation of chemical constitution and the physical properties of steel, carried on at the Physikalisch-Technische Reichsanstalt, Gumlich gives the following formula for computing the specific resistance of pure iron-carbon alloys in the annealed condition. The formula

$$10{\cdot}50 + 3{\cdot}0p + 2{\cdot}0p^2,$$

in which p is the weight percentage of carbon, was obtained from measurements on selected steels containing from 0·21 to 0·76 per cent. of elements other than iron and carbon, corrections being made for the probable effect for those other elements on the specific resistance. From this formula the specific resistance of a pure 0·90 per cent. iron-carbon alloy would be 14·82 microhms at 20° C.; if the measurement were made at 25° C. this value would be increased by 0·2 to 0·3 microhm.

Among the series of nearly pure iron-carbon alloys given in the literature is one of seventeen steels described by Stäblein.[1] In this series the carbon varied from 0·05 to 1·65 per cent., and the elements other than iron and carbon (Mn, Si, P, S, Cu, Ni, Cr) varied between 0·28 and 0·46 per cent. The presence of these latter elements necessitated deductions of from 1·77 to 3·77 microhms from the observed specific resistances, in order to give the specific resistance of iron plus carbon alone. Measurements were made at 20° C., and the specific resistance given for annealed steel containing 0·90 per cent. carbon was 14·7 microhms; this would be between 14·9 and 15·0 microhms at 25° C.

In 1924 Yensen[2] gave a formula for computing the specific resistance of pure iron-carbon alloys:

$$\rho = 9{\cdot}6 + 82{\cdot}5\,\mathrm{C} + 4{\cdot}5\,(\mathrm{C} - 0{\cdot}02),$$

in which 9·6 was taken as the specific resistance of pure iron at 20° C., the first C the percentage of carbon under 0·02 per cent.,

[1] Fritz Stäblein, "Ueber den Einfluss des gebundenen Kohlenstoffs auf den Spezifischen Widerstand des Eisens," *Zeitschrift für Physik*, 1923, vol. xx. pp. 209–228.

[2] Dr. T. D. Yensen, "Magnetic and Electrical Properties of the Ternary Alloys Fe–Si–C," *Journal of the American Institute of Electrical Engineers*, 1924, vol. xliii. p. 566.

and the second C that in excess of 0·02 per cent. By this formula the specific resistance of a 0·90 per cent. carbon steel, annealed, would be 14·87 microhms at 20° C.

In 1924 one of the authors with G. W. Whitney [1] gave specific resistance measurements on some 6 millimetre square bars of carburised Armco iron, a value of 13·79 microhms per cm.³ at 25° C. having been found. In another paper [2] the same authors reported a value of 13·86 microhms per cm.³ at 25° C. for a 0·90 per cent. carbon round bar, 6·3 millimetres in diameter, carburised like the preceding and, like them, slowly annealed in dry hydrogen after equilibration.

The literature contains no reports of specific resistance measurements on steels of varying carbon content, but in which considerable amounts of elements other than iron and carbon have been kept strictly constant throughout each series, except the chrome steel and chrome-tungsten steel referred to above.

The most comprehensive research which has appeared on the thermo-electric properties of special steels is that published by Dupuy and Portevin.[3] From a study of a series of six steels, containing carbon ranging from 0·07 to 1·58 per cent., and in which the sum of all elements other than iron and carbon ranged from 0·048 to 0·146 per cent., they came to the conclusion that the increase in thermo-electromotive potential in pure iron-carbon alloys was a linear function of the carbon content, the increase being at the rate of 4·6 microvolts per degree for 1 per cent. carbon in annealed steels, and at the rate of 13·9 microvolts per degree for 1 per cent. carbon in hardened steel. These values were obtained with a total temperature gradient of from 0° to 100° C. Since, in the special steels studied by Dupuy and Portevin the elements other than iron and carbon were intentionally varied widely, the effect of variations in carbon content alone on the thermo-electromotive potential could not be studied. There are no data

[1] E. D. Campbell and G. W. Whitney, "The Effect of Changes in Total Carbon and in the Condition of Carbides on the Specific Resistance and on Some Magnetic Properties of Steel," *Journal of the Iron and Steel Institute*, 1924, No. II. p. 291.

[2] E. D. Campbell and G. W. Whitney, "A Laboratory Method for the Preparation of Small Steel Bars Differing only in Carbon Content, and the Effect of Changes in Carbide Concentration on the Specific Resistance," *Transactions of the American Society for Steel Treating*, 1924, vol. vi. p. 33.

[3] E. L. Dupuy and A. M. Portevin, "The Thermo-Electric Properties of Special Steels," *Journal of the Iron and Steel Institute*, 1915, No. I. p. 306.

in the literature showing the influence of changes in carbon content alone on alloy steels where the elements other than iron and carbon have been kept strictly constant.

The object of the present research was to obtain additional data showing the influence of changes in total carbon content on the specific resistance and on the thermo-electromotive potential of nearly pure iron-carbon alloys and of derivatives from three alloy steels, comprising a nickel, a chrome-nickel, and a chrome-vanadium steel.

Materials Used.

The bars used were derivatives obtained by carburising, decarburising, and equilibrating 6·3 millimetres diameter round bars of four "basis" metals by methods substantially similar to those described in the two previously mentioned papers by one of the authors and G. W. Whitney. The basis metals comprised:

(OA1) Armco iron.
(OH2) a standard nickel steel (Society of Automotive Engineers, Steel No. 2320).
(OH3) a standard chrome-nickel steel (S.A.E., No. 3312).
(OH4) a standard chrome-vanadium steel (S.A.E., No. 6150).

The round Armco iron bars were drawn down and furnished through the courtesy of the Page Steel and Wire Company, and the three alloy steels were supplied in the form of straight, smooth-rolled bars by the Halcomb Steel Company. The chemical composition of the four "basis" metals is given in Table I., while the atomic concentration showing the milligramme atoms of each element in 1 cubic centimetre is shown in Table II.

Table I.

Table giving the composition in weight per cent. of the four "basis" metals used in preparing the series.

Steel.	S.A.E. Steel. No.	C. Per Cent.	Mn. Per Cent.	P. Per Cent.	S. Per Cent.	Si. Per Cent.	Cr. Per Cent.	Ni. Per Cent.	V. Per Cent.	Cu. Per Cent.	Fe. Per Cent.	Total. Per Cent.
OA1	1001	0·01	0·028	0·003	0·018	trace	...	...	...	0·039	99·90	100·00
OH2	2320	0·16	0·63	0·013	0·014	0·19	...	3·50	...	...	95·49	100·00
OH3	3312	0·14	0·33	...	...	0·24	1·50	3·69	...	...	94·10	100·00
OH4	6150	0·58	0·69	0·023	0·016	0·26	0·99	...	0·20	...	97·26	100·00

TABLE II.

Table giving the atomic concentration in milligramme atoms per cubic centimetre of the four "basis" metals, computed from Table I. by applying the formula $\frac{10D \times \text{wt. per cent. A}}{\text{atomic wt. of A}}$, in which D is the weight in grammes of 1 cubic centimetre of the steel, and A the element in question.

Steel.	S.A.E. Steel. No.	C.	Mn.	P.	S.	Si.	Cr.	Ni.	V.	Cu.	Fe.	Total.
OA1	1001	0·065	0·040	0·008	0·044	...	...	...	...	0·048	140·26	140·47
OH2	2320	1·04	0·92	0·033	0·034	0·53	...	4·67	...	...	134·11	141·35
OH3	3312	0·91	0·47	...	...	0·66	2·25	4·91	...	...	131·76	140·96
OH4	6150	3·77	0·98	0·058	0·039	0·72	1·48	...	0·31	...	136·16	143·52

PREPARATION OF BARS.

The method used for preparing bars was a slight modification of that described by one of the authors with G. W. Whitney before the Institute a year ago, and given in more detail before the American Society for Steel Treating. It had been discovered that the presence of occluded gases caused a slight increase in the specific resistance of hypoeutectoid steels, and a much larger increase, amounting in some cases to over 1·5 microhms, in hypereutectoid steels. It had also been found that if, in annealing, the cooling was so slow that marked spheroidisation of the precipitated carbides took place, the specific resistance was less by 0·1 or 0·2 microhm than if the annealing took place at a "medium" rate. If the heating current was cut off, the temperature fell at such a rate that it needed about forty minutes to drop through the first hundred degrees, the time increasing gradually for the succeeding lower temperatures. In the cases of all bars used in the present work, after equilibration the furnace was allowed to cool at a medium rate from 950° C. to room temperature, the bars being kept meanwhile in an atmosphere of dry hydrogen. When the furnace was cold the silica tube containing the bars was evacuated by means of a Cenco-Hyvac pump, and the stopcocks at both ends of the tube closed. The temperature was then raised to 800° C. and held there for one hour, when the stopcock at the outlet end, connected to a manometer, was

opened; the latter then showed approximately the amount of gas that had been liberated from the steel. This amounted to from 6 or 8 to as much as 60 cubic centimetres in a few instances. This gas was pumped out, after which the stopcocks were closed and the heating current cut off, and the bars thus given a medium vacuum anneal from 800° C.

An approximate idea of the relative affinities of the different steels for carbon may be obtained by an examination of the equilibration data shown in Table III., in which are given the experimental data found in part of the experiments used in preparing the different series of bars.

TABLE III.

Carb. Exp. No.	Equi. Exp. No.	Before Equilibration.								After Equilibration.			
		No. Bar.	OA1. C per Cent.	No. Bar.	OH2. C per Cent.	No. Bar.	OH3. C per Cent.	No. Bar.	OH4. C per Cent.	OA1. C per Cent.	OH2. C per Cent.	OH3. C per Cent.	OH4. C per Cent.
...	154	11	0·01	...	...	11	0·14	...	...	0·05	...	0·10	...
...	152	11	0·01	11	0·16	...	...	...	...	0·07	0·10	...	...
...	168	14	0·01	...	...	...	...	7	0·58	0·10	...	...	0·23
...	157	14	0·01	...	...	...	...	7	0·58	0·16	...	...	0·28
...	158	...	...	...	...	14	0·14	7	0·58	...	...	0·25	0·38
...	155	...	...	14	0·16	...	...	7	0·58	...	0·25	...	0·40
...	163	...	...	...	...	7	0·14	14	0·58	...	...	0·34	0·48
...	156	...	...	7	0·16	...	...	14	0·58	...	0·33	...	0·49
171	172	...	...	7	0·50	7	0·44	7	0·91	...	0·48	0·53	0·73
169	170	...	...	7	0·73	7	0·71	7	1·07	...	0·70	0·76	0·97
173	174	7	0·86	7	0·75	7	0·79	...	...	0·82	0·70	0·77	...
175	176	...	...	7	0·95	7	1·04	7	1·38	...	0·84	1·05	1·37
177	178	...	...	7	0·97	7	1·08	7	1·82	...	0·92	1·13	1·65
182	184	...	...	7	1·20	7	1·45	7	1·43	...	0·91	1·41	1·66
189	190	8	1·53	7 7	0·91 1·33	...	...	...	...	1·21	1·02 1·16	...	...

"No. bar" refers to the number of bars used in the experiment.

HEAT TREATMENT OF BARS.

All annealed bars, before measurements of specific resistance or thermo-electromotive potential were made, were given a "medium" vacuum anneal from 800° C., as previously described.

The hardened bars were all quenched in a large volume of water at 1° to 2° C., about 30 litres of water being used, so that

the temperature was not raised more than 2° or 3° by the quenching of twelve bars. The bars were kept suspended in the heating furnace for forty minutes after attaining the temperature from which it was intended to quench in order to allow them to come to substantially the same conditions as they were in during equilibration. Two improvements in the technique of hardening have been introduced in the manipulation of the bars used in the present investigation. Experience had shown that nearly carbon-free bars suspended for an hour or more in the heating furnace, which contained essentially an atmosphere of carbon monoxide and nitrogen, would become slightly carburised on the surface, the extent of this carburisation being enough to increase the specific resistance of the hardened bars about 0·2 to 0·3 microhm, and the thermo-electromotive potential 0·5 microvolt. Three years ago one of the authors[1] showed that when small bars were quenched in a vertical position the end of the bar last entering the quenching medium cooled more rapidly than the end first touching the quenching bath, and, in consequence, there was more or less difference in physical constitution along its length. In order to obviate this lack of uniformity, the bars were suspended in the heating furnace by means of two long chromel wire hooks, one attached to each end of the steel bar. By this means a bar could be raised out of the heating furnace and simultaneously brought to a horizontal position just before entering the quenching bath. Before hardening the bars were all electroplated with copper, in order to prevent surface carburisation during the time they were suspended in the heating furnace. The copper was removed from the electroplated bars after quenching by covering the bars with concentrated ammonia to which was added a little ammonium persulphate, and allowing them to stand until the copper was dissolved; after washing and wiping, the bars thus treated were found to be as smooth and bright as before plating.

Specific Resistance.

Specific resistances were determined in the usual way by measuring the fall in potential between knife-edges 10 centimetres apart, permanently bolted to a small glass plate, so that the bar

[1] E. D. Campbell, "A Brinell Machine Attachment for Use with Small Specimens," *Journal of the Iron and Steel Institute*, 1922, No. II. p. 193.

could be suspended during the time of measurement in an oil-filled thermostat and maintained at 25° C., with a variation of not more than 0·01° C. for weeks at a time. A standard 0·001 ohm resistance, certified by the Bureau of Standards, was kept in series with the bar, and all measurements were checked by comparison with the standard resistance. The fall in potential was measured with a Leeds and Northrup precision potentiometer, using a Bureau of Standards certified standard cell.

Thermo-Electromotive Potential.

The special apparatus used for measuring thermo-electromotive potential is shown in Fig. 1, and consisted essentially of a holder (A) made from a 6 millimetre square bar of electrolytic iron firmly fitted into a foot-piece (B) made of the same material. The electrolytic iron was part of a stock of this material supplied by the Bureau of Standards, and was decarburised by treatment with hydrogen at 950° C. for seven days, followed by very slow annealing from this temperature. At the points (C) and (C′) small holes were drilled about 5 millimetres deep and connected by a groove 1 millimetre wide and 1·5 millimetre deep. A differential copper-advance thermocouple was inserted in these holes and the wires were placed in the groove connecting the holes, both the thermocouples and wires being carefully insulated to avoid short circuiting. The thermocouples were calibrated, and gave a potential of 39·3 microvolts for a temperature difference of 1° C. The temperature gradient, therefore, between the points (C) and (C′) could be easily measured by means of a precision potentiometer to within less than 0·01° C. An adjustable hard rubber block (D) was attached to the holder and served to carry the weight of the system when in use, and also to hold in position the bar (E) which was being tested. The caps (F) and (F′) were firmly attached to the tops of the holder and bar, and connected by means of heavy wires to the adjustable support (G), which also carried two pairs of binding posts by means of which the leads from the differential thermocouple and from the tops of the holder and bar were connected to a Leeds and Northrup precision potentiometer. When in use the holder was lowered through a hole in the bottom of a thermally protected brass container, supported at such a height above the surface of an oil-filled thermostat that the

foot-piece (B), carrying the lower end of the bar under test, was immersed in the oil to a depth of 1 to 2 centimetres. The oil-

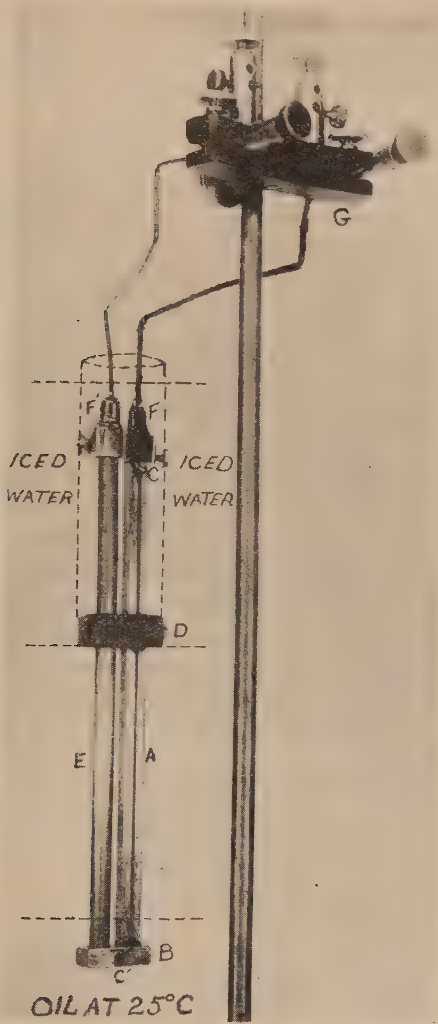

FIG. 1.

filled thermostat was the one used while measuring specific resistances and could be held at 25° C. for weeks at a time if necessary, with a variation of not more than 0·01° C. The

rectangular hole in the bottom of the brass container was just large enough to permit the foot-piece (B) to pass through easily, and was surrounded with a rectangular tubulure 2 centimetres high. A piece of thin-walled rubber tubing, indicated in outline, was fitted over this tubulure, and prevented the ice and water in the metal container from coming in direct contact with the holder and bar. With this apparatus the holder could be readily drawn up through the rubber tubing, a bar to be tested inserted in place, and the holder lowered into position without coming in contact with the water. It was necessary to avoid any water coming in contact with either the holder or bar, especially where the caps were fitted on, as an electromotive force would have been set up by that water, and the results rendered inaccurate. When a new bar had been placed in the holder and the latter lowered into position, about fifteen minutes was required for the temperature gradient to become constant, as indicated by the constancy of potential of the differential thermocouple. The temperature gradient usually varied between 16° and 17° C., according to the proportion of ice and water in the container, but the exact temperature gradient at the time of determining the potential between the holder and bar under examination could be easily checked. When the differential thermocouple showed that the temperature gradient in a given experiment had become constant, the potential of the bar when opposed to pure iron was measured and the results reduced to microvolts for a temperature gradient of 1° C. by dividing the microvolt potential of the bar in the holder by the temperature gradient as determined by the differential thermocouple. Values of thermo-electromotive potential obtained by this improved method were in satisfactory agreement with those obtained by one of the authors with W. C. Dowd and presented to the Institute eight years ago.[1]

Experimental Data.

In Table IV. are given the results of the measurements of the specific resistance at 25° C., and the thermo-electromotive potential for a temperature gradient of 1° C. of the pure iron-carbon series (OA1) in the annealed condition, and one set quenched from 844° C.

[1] E. D. Campbell and W. C. Dowd, "The Influence of Heat Treatment on the Electrical and Thermal Resistivity and Thermo-Electric Potential of Some Steels," *Journal of the Iron and Steel Institute*, 1917, No. II. p. 251.

TABLE IV.—*OA1 Series.*

Bar No.	Weight per Cent. Carbon.	Milatoms per Cm.³	Specific Resistance at 25° C. Microhms.			Thermo-Electromotive Potential. Microvolts per Degree Cent.		
			Annealed.	Quenched 844° C.	Quenched 930° C.	Annealed.	Quenched 844° C.	Quenched 930° C.
				D.	E.		D.	E.
0	0·00	0·00	10·44	...	...	0·04	...	...
1	0·05	0·33	10·66	11·35	11·13	0·45	0·77	0·31
2	0·10	0·65	10·81	11·74	11·81	0·58	1·47	1·59
3	0·16	1·04	10·96	12·29	12·41	0·71	1·33	1·46
3*a*	0·21	1·37	11·07	...	...	0·94	...	...
4	0·27	1·76	11·27	13·92	15·81	1·00	2·73	4·08
5	0·43	2·81	12·00	17·43	18·44	1·84	4·62	5·32
6	0·59	3·85	12·66	23·55	23·84	2·11	7·89	7·88
7	0·66	4·31	12·81	24·73	25·57	2·08	8·15	8·27
8	0·82	5·35	12·87	31·04	31·31	1·51	9·47	10·88
9	0·90	5·88	13·76	31·74	33·21	2·34	11·73	11·81
10	1·05	6·86	13·87	34·48	37·67	2·27	12·32	13·32
11	1·13	7·38	14·89	37·80	41·67	3·12	12·92	14·78
12	1·50	9·80	17·80	39·96	47·58	3·80	12·57	15·55

and another from 930° C. In Tables V., VI., and VII. are given the corresponding results for the three alloy steels OH2, OH3, and OH4, one set of each being measured after vacuum annealing from 800° C. and the other after quenching from either 950° C. or 955° C.

TABLE V.—*OH2 Series.*

Bar No.	Weight per Cent. Carbon.	Milatoms per Cm.³	Specific Resistance at 25° C. Microhms.		Thermo-Electromotive Potential. Microvolts per Degree Cent.	
			Annealed.	Quenched 950° C.	Annealed.	Quenched 950° C.
1	0·006	0·04	24·84	25·32	12·77	12·38
2	0·10	0·65	25·33	27·07	12·96	13·70
3	0·16	1·04	25·59	28·18	13·27	13·83
4	0·25	1·63	26·11	29·82	12·93	14·02
5	0·33	2·15	26·59	31·81	13·55	14·29
6	0·48	3·13	27·41	37·29	13·73	15·47
7	0·65	4·24	28·57	42·62	13·30	16·88
8	0·70	4·57	28·58	43·17	14·11	16·91
9	0·84	5·49	29·38	48·11	14·27	18·39
10	0·92	6·01	30·02	50·66	13·44	19·44
11	1·02	6·66	30·81	54·31	15·13	20·64
12	1·16	7·57	30·71	54·24	15·11	20·44

TABLE VI.—*OH3 Series.*

Bar No.	Weight per Cent. Carbon.	Milatoms per Cm.^{3}	Specific Resistance at 25° C. Microhms.		Thermo-Electromotive Potential. Microvolts per Degree Cent.	
			Annealed.	Quenched 955° C.	Annealed.	Quenched 955° C.
1	0·02	0·13	32·39	33·11	8·51	8·46
2	0·10	0·65	33·07	34·36	8·91	8·88
3	0·14	0·91	33·98	35·46	9·79	9·24
4	0·25	1·63	35·29	37·64	10·14	9·42
5	0·34	2·22	30·83	40·21	11·59	10·68
6	0·53	3·46	28·46	46·60	13·07	12·93
7	0·77	5·02	29·49	52·55	13·56	15·11
8	1·05	6·85	31·05	57·11	14·31	18·29
9	1·18	7·69	31·97	58·77	14·67	19·27
10	1·41	9·19	34·02	57·60	15·41	18·91

TABLE VII.—*OH4 Series.*

Bar No.	Weight per Cent. Carbon.	Milatoms per Cm.^{3}	Specific Resistance at 25° C. Microhms.		Thermo-Electromotive Potential. Microvolts per Degree Cent.	
			Annealed.	Quenched 950° C.	Annealed.	Quenched 950° C.
1	0·09	0·59	24·22	25·41	3·32	4·00
2	0·23	1·50	23·15	26·89	4·20	4·63
3	0·28	1·82	22·90	28·00	4·62	5·17
4	0·38	2·47	22·79	29·87	5·06	6·42
5	0·48	3·12	22·28	32·58	5·64	7·12
6	0·58	3·78	21·78	36·23	5·90	8·81
7	0·73	4·75	21·61	39·68	6·12	10·13
8	0·97	6·31	22·37	45·88	6·41	13·01
9	1·37	8·92	24·38	50·31	7·16	15·70
10	1·65	10·74	25·77	51·81	7·66	16·16

The specific resistances of the four series OA1, OH2, OH3, and OH4 in the annealed condition, as given in the above tables, are shown graphically in Fig. 2, while the specific resistances for the same series in the hardened condition are shown in Fig. 3. In a similar way the results of the thermo-electromotive potential measurements on the annealed samples are shown in Fig. 4, and those on the hardened series in Fig. 5 (p. 15).

An examination of the above-mentioned data and graphs leads

to certain conclusions in regard to the influence of changes in carbide concentration on the specific resistance and thermo-

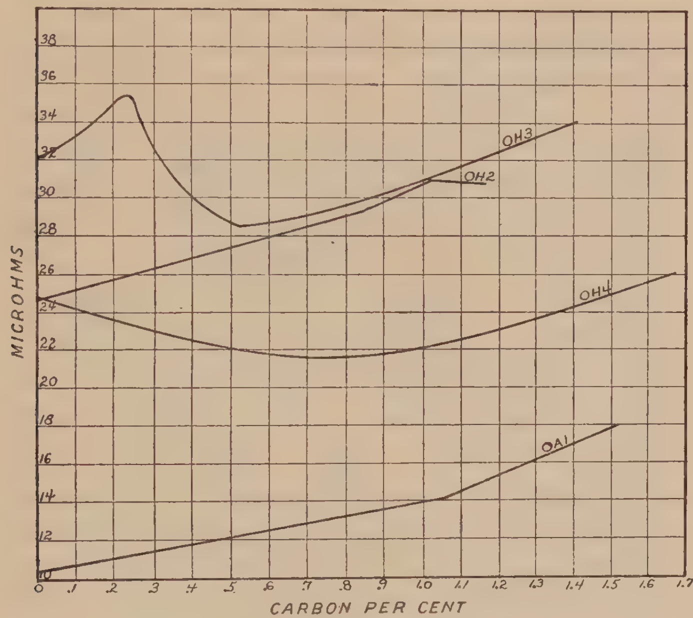

FIG. 2.—Specific Resistances. Annealed Steels.

electromotive potential of the steels studied, which are briefly summarised below.

SUMMARY OF RESULTS OF EXPERIMENTS.

Specific Resistance of Annealed Samples.

1. The specific resistance at 25° C. of the *nearly* pure iron-carbon series (OA1) corresponds to the formula

$$10{\cdot}44 + 3{\cdot}7\ C$$

up to a carbon content of 1·1 per cent., and

$$14{\cdot}51 + 7{\cdot}8\ (C - 1{\cdot}1)$$

up to 1·5 per cent. carbon.

An absolutely pure iron-carbon series would have a specific resistance at 25° corresponding to the formula

$$10{\cdot}0 + 3{\cdot}7\ C$$

for carbon content up to 1·1 per cent., and

$$14 \cdot 07 + 7 \cdot 8\ (C - 1 \cdot 1)$$

when the carbon increased up to 1·5 per cent.

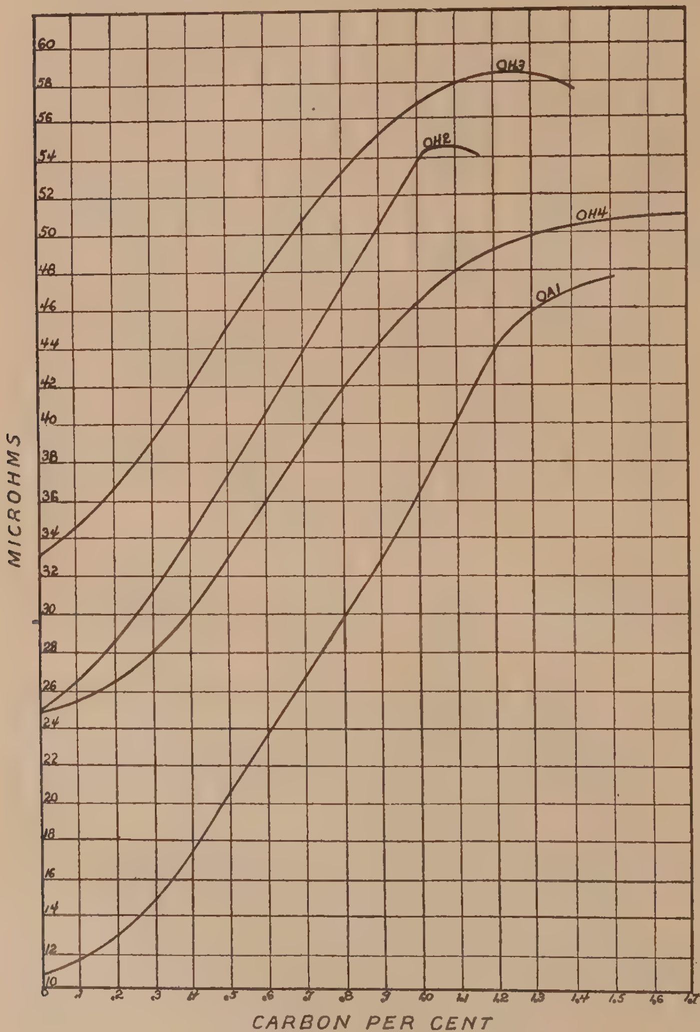

FIG. 3.—Specific Resistances. Hardened Steels.

2. The increase in the specific resistance of the nickel steel series (OH2) with increase of carbon content up to 0·92 per cent.

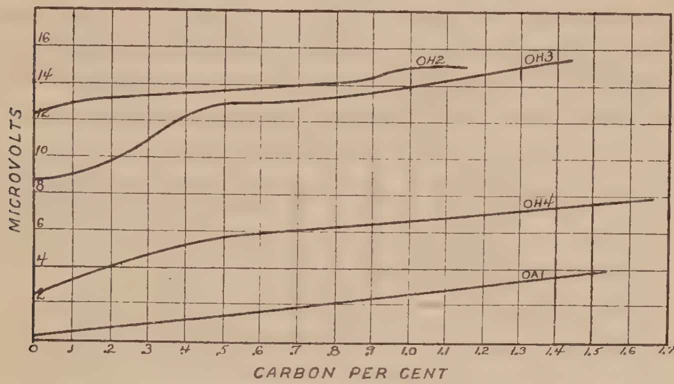

FIG. 4.—Thermo-Electromotive Potential. Annealed Steels.

is at the rate of 5·7 microhms for 1 per cent. of carbon, as contrasted with 3·7 in the case of the pure iron-carbon series. This

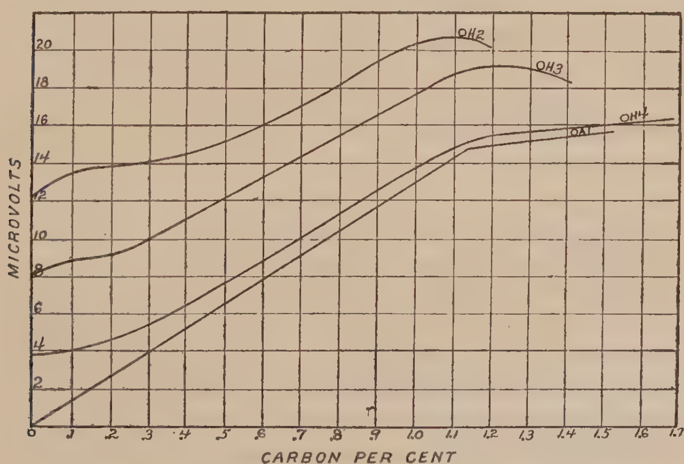

FIG. 5.—Thermo-Electromotive Potential. Hardened Steels.

would seem to indicate that the presence of nickel increases the solvent power of α-iron for carbides. The rate of increase of

specific resistance of nickel steels with more than 1·0 per cent. carbon is less than in the case of pure iron-carbon alloys.

3. In the case of the chrome-nickel series (OH3), the increased solvent power of α-iron for carbides caused by the presence of nickel is clearly indicated by the rapid rise in the specific resistance up to a point where the carbon concentration is equal to or slightly greater than that of the chromium, when the precipitation of the double carbides of iron and chromium causes a sudden drop in the specific resistance. The minimum specific resistance is found when the carbon concentration is twice that of the chromium, but when the chromium has been largely precipitated the rate of increase of specific resistance is only slightly less than in the hyper-eutectoid pure iron-carbon alloys. This minimum specific resistance of annealed chrome steels, when the carbon concentration is about twice that of the chromium, was also shown in the 2·23 per cent. chrome steel reported to the Institute a year ago.[1]

4. In the absence of any nickel the chrome-vanadium series (OH4) shows a continuous fall in specific resistance down to a minimum, which, however, is not reached until the carbon concentration is at least 2·6, or probably three times that of the chromium and vanadium together. With further increase of carbon concentration there is a rise in specific resistance, the rate of increase being, however, less in the proportion of 5 to 7·1 than that of the chrome-nickel series, which in turn is less than that of the pure iron-carbon alloys.

Thermo-Electromotive Potential of Annealed Samples.

1. The thermo-electromotive potential of the nearly pure iron-carbon series (OA1) increases at the rate of 2·3 microvolts for 1 per cent. carbon all the way up to 1·5 per cent. Probably the thermo-electromotive potential of a series of strictly pure iron-carbon alloys would not differ appreciably from these values.

2. The thermo-electromotive potential of the nickel steel series (OH2) increases at about three-fourths of the rate of that of the pure iron-carbon series (OA1) up to about 1·0 per cent. carbon, after which the rate of increase is still smaller.

3. In the chrome-nickel series (OH3) the rate of increase of

[1] See footnote 1, p. 377.

the thermo-electromotive potential is more than three times that of the pure iron-carbon series up to a point where the carbon concentration is twice that of the chromium, after which the rate of increase is only slightly greater than that of the pure iron-carbon series.

4. In the case of the chrome-vanadium series (OH4) the rate of increase in the thermo-electromotive potential is more than twice that of the pure iron-carbon series up to a carbon concentration of twice the sum of the chromium and vanadium, after which the rate of increase falls off to only a little more than two-thirds of that of pure iron-carbon alloys.

Specific Resistance of Freshly Hardened Samples.

1. In the two sets, E and D, of the pure iron-carbon series (OA1), the rate of increase in the specific resistance of Set E (quenched from 930° C.) is a little greater than that of Set D (quenched from 844° C.) until the neighbourhood of the eutectoid concentration is reached. When the carbon is above 0·90 per cent. the dissociation of the pro-eutectoid cementite is much greater at 930° than at 844° C., as is clearly indicated by the decidedly higher specific resistance of the E set. Since both the temperature from which the steel is quenched and the rate at which the metal passes through the critical range in cooling have such a marked effect on the specific resistance, no attempt has been made to work out a formula by means of which the specific resistance of hardened steel may be computed.

2. In the nickel steel series (OH2) the rate of increase in specific resistance is slightly greater than for the pure iron-carbon series up to about 1·0 per cent. carbon. In the one case carrying noticeably over 1·0 per cent. carbon, there is a slight fall in the specific resistance.

3. The chrome-nickel series (OH3) has a slightly smaller rate of increase in specific resistance than the pure iron-carbon series up to about 1·0 per cent. carbon, but above this amount the increase is very much smaller than in the case of the pure iron-carbon alloys.

4. The chrome-vanadium series (OH4) shows that the rate of increase in specific resistance is about nine-tenths of that of the

pure iron-carbon series up to 1·0 per cent. carbon, but above this concentration the rate of increase is less than half that of the pure iron-carbon alloys.

Thermo-Electromotive Potential of Freshly Hardened Samples.

1. In the pure iron-carbon series, Set E (quenched from 930° C.), the thermo-electromotive potential increases directly as the carbon concentration increases at the rate of 12·8 microvolts for 1 per cent. carbon, as compared with the rate of 2·3 microvolts for 1 per cent. carbon when the steels are in the annealed condition.

2. In the nickel steel series (OH2) the rate of increase in thermo-electromotive potential is at the rate of 7·4 microvolts for 1 per cent. of carbon up to 1·0 per cent., in contrast to 12·8 microvolts for the pure iron-carbon alloys. In the single case of nickel steel with much more than 1·0 per cent. carbon, there is a slight fall in the microvolts, as there was in the specific resistance.

3. In the chrome-nickel series (OH3) the increase of thermo-electromotive potential is at the rate of 4·2 microvolts for 1 per cent. carbon, up to the point where the carbon concentration is equal to or greater than that of the chromium, where there is an abrupt rise to a rate of increase of 12·3 microvolts for 1 per cent. carbon, which continues to a carbon content of 1·18 per cent. On the one sample above 1·18 per cent. carbon, there is a fall in both the thermo-electromotive potential and specific resistance.

4. The thermo-electromotive potential of the chrome-vanadium series (OH4) increases at the rate of 11·4 microvolts for 1 per cent. carbon up to about 1·0 per cent., after which there is a very marked falling off in the rate of increase in both the thermo-electromotive potential and the specific resistance.

1926, No. I.; Vol. CXIII. Annual Meeting, June 3–4.

Iron and Steel Institute.

MAGNETIC CHANGES IN IRON AND STEEL BELOW 400° C.*

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1. INTRODUCTION.

THAT there are several singular points in the properties of iron and steel at low temperatures has been known for some considerable time. Borelius and Gunneson [1] investigated these changes, using a thermo-electric method in which iron and steel wires, quenched from gradually ascending temperatures, were made into couples with untreated wires of the same composition. The thermo-electric power of each couple was measured and plotted against the quenching temperature. From the curves thus obtained it was considered that iron undergoes a considerable number of changes which occur at approximately equal temperature differences. An explanation of these so-called "Z-changes" was attempted even on the basis of the quantum theory.

Heraeus [2] published a repetition and criticism of that work, and showed that the experimental method adopted was very liable to error.

Thompson and Goffey,[3] by means of careful measurements of the torsional elastic limit, demonstrated the existence of two remarkably sharp minimum points near 120° C. and 270° C. respectively—points previously observed by other workers. Other sharp bends were found in the curves, but they scarcely gave evidence in favour of the supposed large number of "Z-changes." Electrical resistivity measurements were also made, but the results appear to be rather variable, and do not permit definite conclusions to be drawn.

Thompson and Whitehead [4] had previously found change points in iron at 55°, 120°, 220°, and 245° C., those at 120° and

* Received November 6, 1925.

220° C. being most important. In high-carbon steels two points were found—at 160° and 200° C. These were both ascribed to changes in the carbide, but the authors were unable to decide whether they were distinct points or the ends of a single transformation range.

Now the magnetic properties of iron being known to be rather sensitive to physical and molecular changes, it appeared probable that, if these low-temperature changes did actually exist, there should be parallel changes in the magnetic properties. For this reason the present work was undertaken.

Only a comparatively small number of workers have studied the changes in the magnetism of iron at low temperatures, the literature of which has been carefully surveyed by Dejean.(7) Besides the researches of the latter, those of Smith (5) and of Honda (6, 10, 11) and his collaborators are the only ones which have to be considered here.

Smith studied the thermo-magnetic properties of a steel containing 0·85 per cent. carbon and found that the magnetisation attained a maximum at 210° C. This was attributed to a magnetic change in the cementite.

Honda and Takagi investigated twelve plain carbon steels and found a similar change of magnetisation. Using a constant magnetic field, the maximum magnetisation was found at about 170° C., followed by a decided loss, the magnitude of which varied with the amount of free cementite present in the steel. In a subsequent paper the authors confirmed the cementite change, stating that the critical temperature was 215° C.

If the change at 215° C. is really due to Fe_3C, then it should not be observed in fully hardened steels. Honda has shown that this is the case by heating quenched steels to successively higher temperatures, and taking the magnetisation-temperature curves in a constant field on heating and on cooling. A quenched specimen heated up to 260° C. did not show the cementite point; one heated to 325° C. showed a loss of magnetisation at about 275° C., and on cooling the carbide change was clearly visible, showing that free carbide had precipitated during the heating.

Dejean (7) obtained induction-temperature curves in an alternating field, using a photographic method for registering the curves direct. A series of steels, of carbon content varying from 0·06 per

cent. to 1·66 per cent., was studied and the magnetic transformation of cementite found to occur at about 200° C. It was observed in general as a minimum in the value of the induction. The general form of the induction-temperature curves was stated to depend on the dimension ratio of the specimen, and when this was small the induction was independent of the temperature until reaching A2. Certainly, the cementite change is scarcely visible in the published curves for low dimension-ratio specimens.

Four curves were given for steels quenched from 1000° C. The carbide change was entirely suppressed on the heating curves, and there then appeared a remarkable maximum at 300° C. Attention was drawn to the fact that an analogous point was found in 1913 by Charpy and Grenet in the dilatation curve of 0·93 per cent. carbon steel quenched from 925° C. In only one case was the cooling curve given after heating the specimen to 800° C., and in it the 300° point was replaced by the cementite transformation at about 220° C.

Dejean does not appear to have observed any other points beyond the one due to cementite, and the 300° C. point in quenched steels. His work was more concerned with the important magnetic change at 760° C.

2. Description of Apparatus.

In working out the details of the present research it was decided to use a photographic method, on the magnetometer principle, to register directly the temperature-magnetisation curves of the specimens, thus obtaining a continuous and sensitive record, practically independent of the observer. It was not considered necessary to make determinations of an absolute character, but efforts were concentrated on the exclusion of external influences, such as vibration, &c.

General Arrangement of Apparatus.—The disposition of the various components of the apparatus, together with the electrical circuits, is shown in Fig. 1.

A beam of light from a pin-hole in the front of the lamp *A* passed through a condensing lens *B*, and was reflected through an angle of about 30° by the plane mirror of a moving-coil galvanometer *G*. The beam then passed through a totally

reflecting prism arranged to transform horizontal deflections due to the galvanometer into vertical motions. Finally the light was reflected through about 60° at the surface of the mirror in the magnetometer *M*, and passing down the camera *C* produced

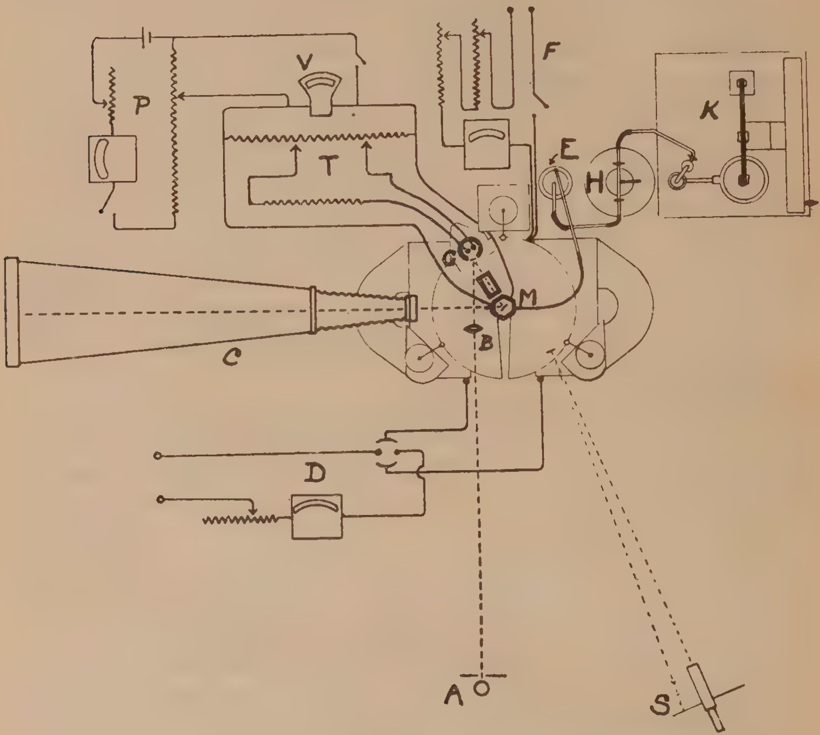

Fig. 1.

a spot of light on a sheet of bromide paper, which registered the motion of the spot during an experiment.

The magnetometer mirror registered as horizontal deflections of the beam of light the motion of the specimen, itself used as the magnetometer needle, as it was heated while suspended in an horizontal position in a constant magnetic field, and at about 45° with the direction of the latter. Simultaneously the galvanometer and prism gave the beam of light a vertical deflection nearly proportional to the temperature of the specimen, as

measured by a thermocouple placed immediately below it. Hence the spot of light traced a temperature-magnetisation curve, with magnetisation as abscissæ and temperatures as ordinates.

Of the three circuits shown in Fig. 1, *D* belonged to the electro-magnet, giving the constant magnetic field; the furnace was heated by alternating current in the circuit *F*. The thermocouple circuit, *T*, was slightly more complicated. Of the E.M.F. generated by the thermo-junction, the main part was utilised in the direct reading millivoltmeter, *V*, while a small fraction of the remainder was employed to deflect the galvanometer *G*. By means of the circuit *P*, known E.M.F.'s could be impressed on the thermocouple circuit, to enable the sensitivity of the registering galvanometer to be adjusted, and also to ascertain that the instrument was swinging freely—a necessary precaution before commencing any experiment, as will be understood later.

During the experiments the magnetometer was exhausted to a pressure of just under 0·1 millimetre by the Volmer mercury pump *E*, which worked in front of a large glass bottle, *H*, kept at a pressure of 1·0 millimetre by means of a Leybold hand-pump, *K*. Owing to the unavoidable use of rubber tubing, the vacuum obtained in the magnetometer was never good enough to prevent oxidation entirely; a specimen practically always showed a slight blue-grey tinge after testing.

The camera had a length of 120 centimetres, and the total distance between the magnetometer mirror and the focusing screen was 145 centimetres. So as to be independent of any subsequent paper shrinkage a screen (*réseau*) was used, which, after exposure, gave a system of black reference lines when the paper was developed.

Magnetic Field and Magnet.—The external field was set up in the gap of a large Hartmann and Braun electro-magnet and kept constant at 15 gauss. The diameter of the pole faces was 93 millimetres and the gap width 79 millimetres.

The uniformity of the field was tested for various strengths and gap widths. For fields between 2500 and about 2 gauss it was found that, within a cylinder 30 millimetres in diameter, described about the axis of the poles, the magnetic field was quite uniform and symmetrical; this was quite large enough for the purposes in view. Any change in the earth's field was found to be

without effect on the magnet field, even when the latter was as low as 2·25 gauss.

The Magnetometer.—The features of this instrument are shown in Fig. 2.

Tube A was made of ordinary glass, and sealed in position with "Chatterton compound." The upper end was carefully ground to accommodate the torsion head carrying the suspension. Tube B was made of "Pyrex" glass, internal diameter 13·5 millimetres and external 16·3 millimetres, and was held in position by hard-setting wax, protected by a few turns of asbestos string, soaked in sodium silicate.

The body of the magnetometer D was a length of hollow hexagonal brass rod, with two adjacent faces drilled, to form the housing of the magnetometer mirror. The two openings were each covered with a thin glass plate sealed in position, thus forming two windows, for the entering light and the beam reflected from the mirror. Each of the two glass tubes E, F, was fixed with hard wax in holes drilled in the body of the instrument, and each carried one of the thermocouple wires, the constrictions enabling the latter to be easily sealed in. The Volmer pump was connected to tube G by a length of pressure tubing painted over with shellac. The lower part of the body of the magnetometer was constructed as a water-cooler to prevent undue heating of the sealing of the "Pyrex" tube. The entrance and exit tubes for the water are shown at H. The magnetometer was held vertically by a clamp engaging on the rod K. As, however, the internal diameter of the lower tube was 13·5 millimetres and the length of the specimen was 10 millimetres, a means of fine adjustment was provided by two set-screws L, M, which permitted a slight movement in two directions at right angles, after the instrument had been set as correctly as possible with the clamp.

The Suspension of the Specimen.—Fig. 3 shows the suspension for the specimen. At the top is the torsion head carrying the arms of the bifilar suspension. By rotating the upper milled-head, A, the small brass piece, B, could be raised or lowered. On rising it came into contact with projections on the arms P, P, pressed them outwards, and thus increased the stiffness of the suspension. Reversing the process allowed the arms to close, and so made the suspension more sensitive. A was provided with

a pointer which moved over a scale of degrees engraved on *C*,

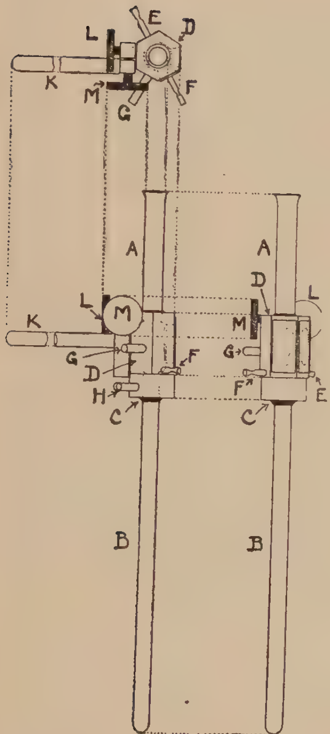

FIG. 2.

FIG. 3.

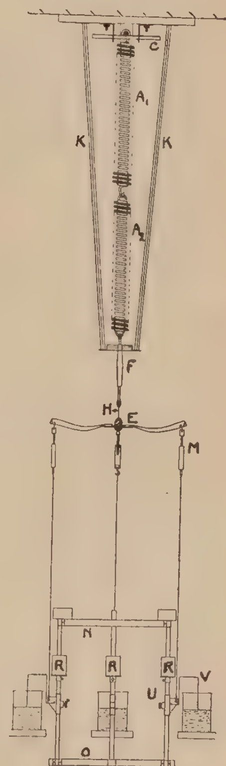

FIG. 4.

and a simple calibration gave the width of the bifilar gap at *R* in terms of degrees of rotation of *A*. The lower part of the suspension

was provided with an oblong mirror *M* (30 millimetres long) to allow for the vertical movement of the beam of light.

The specimen was carried on the hooks at the lower end of the stirrup *N*, made of silica rod 0·5 millimetre in diameter. A third inverted hook, pressing down on the centre of the specimen, kept it in position.

The Thermocouple.—When inside the magnetometer, the specimen hung about 4 millimetres above a platinum-platinum-rhodium thermo-junction, soldered to the centre of a silver disc.

The thermocouple was carefully calibrated for temperatures up to 300° C. against a Siebert and Kühn nitrogen-filled thermometer, and up to 700° C. against a standard platinum-platinum-rhodium couple calibrated at the Physikalisch-Technische Reichsanstalt (Berlin).

The Furnace consisted of a vertical porcelain tube 160 millimetres long, closed at the lower end. Its internal diameter was 18·5 millimetres and external 23 millimetres. A length of 105 millimetres was wound with platinum ribbon, held in place by longitudinal threads of alundum cement. The heating element was placed centrally in a porous pot, and kept in position by two collars of turned soapstone. The whole fitted closely into a brass water-cooler, used to protect the magnet poles between which the furnace was placed. No packing material was used between the heating element and the porous pot, so that the whole arrangement had only a small heat capacity. The clearance between the magnetometer and the furnace was 1 millimetre.

3. The Elimination of Vibration.

Although the principles of the experimental method were perfectly simple, the nature of the apparatus demanded considerable freedom from vibrations, and the exclusion of these disturbances was only successfully accomplished by materially complicating the design of the whole arrangement.

Very considerable help was derived from the work of Julius,[8] and a suspension was designed to carry the magnetometer and galvanometer together on one platform, suspended from the roof of the laboratory (Fig. 4).

A hook at the top of the two springs A1, A2 was clamped to a short steel bar resting in a V-groove in another one, *C*, at right angles to it. Both bars could move in the direction of their length, so that the position of the whole suspension could be adjusted over the magnet. The lower end of A2 and the plate *E* were connected by a turnbuckle *F*, and a link *H* of fine piano wire passing round the hook in the plate and through the lower eye-bolt. Pieces of oiled felt were placed between every coil in the springs, while slight damping was applied to the nut of the turnbuckle by rings of oiled felt, supported on a thin steel plate, carried by three wooden stays, *K*, *K*.

From the plate *E* three steel arms, inclined to one another at angles of 120°, extended, and carried at their outer ends adjustable shackles *M*, from which the cage carrying the magnetometer and galvanometer was suspended by stranded copper wires 1 millimetre in diameter. The cage comprised two platforms, *N*, *O*, connected by three vertical brass tubes. *N* was a hollow equilateral triangle, while *O* was a circular disc 36·5 centimetres in diameter, with a slot cut from the circumference to the central hole, so that the magnetometer could be placed in position conveniently. The vertical stays were provided with adjustable weights *R*, and were also engraved with a scale of half centimetres. The brass hooks carrying the cage, and the holes in the movable wings *U*, through which they passed, were filed to knife-edged contacts, to minimise friction.

The dampers, *V*, of brass wire 2·5 millimetres diameter, dipped just below the surface of ordinary machine oil, in beakers carried on small wooden platforms affixed to the magnet; the damping had to be very weak, otherwise vibrations were transmitted from the magnet, through the oil, to the suspended system.

A light triangular platform, fixed to the lower platform so as to project some 7 centimetres over the edge, was provided with clamps for holding the galvanometer in its correct position relative to the magnetometer, and heavy counterbalancing weights were placed on the upper platform of the cage.

The clamp carrying the magnetometer was fixed to a short vertical column bolted in a slot in the lower platform. This slot was cut concentrically with the circumference of the disc, so that

within limits the magnetometer could be adjusted to its correct angular position with regard to the galvanometer. Provision was made for arresting the cage when necessary.

The adjustments of the suspension were made on the principles laid down by Julius; as the magnetometer was more sensitive to disturbance than the galvanometer, it was decided that efforts made to protect the magnetometer would automatically safeguard the galvanometer.

Finally, in order to reduce still further the possibility of external vibrations affecting the results, the whole of the experimental work was carried out at night.

4. Experimental Procedure.

Having arrested the main suspension the specimen was placed in position and then reversed twelve times in the magnetic field by rotating the torsion head. It was then brought into a standard position at an angle of 45° with the field and the cage released. As there was a danger that the latter might rotate, its position was controlled before and after an experiment by means of the simple telescope, mirror, and scale arrangement depicted diagrammatically at *S* (Fig. 1). No movement was found to occur if sufficient care were taken with all the preliminary operations.

During a registration the temperature of the specimen was raised about 20° C. per minute. This rate of heating was chosen because: (1) The risk of vibrations reaching the apparatus rendered it desirable that each registration should be carried out fairly quickly; (2) with higher rates of heating there was the possibility of a considerable lag of the temperature of the specimen behind that of the thermocouple.

The temperature calibration of the curves was obtained as follows:

The illuminating lamp was switched out when the pyrometer on the control table registered a temperature 5° C. lower than 100° C., and switched on again when it registered 5° C. above. This was repeated for 200°, 300°, and 400° C. On the final curve the 100° C. point, for example, could be located at the centre of the first gap in the curve.

The registration was usually carried up to 450° C. The furnace

having cooled again, the specimen was brought back to its original magnetic condition, by reversing it twelve times in the magnetic field, as previously described, and then turned to the standard position and the experiment repeated. The same paper was kept in the camera, which was moved about 2 centimetres horizontally to prevent the curves from coinciding.

5. Dimensions and Compositions of the Specimens.

The analyses of the various irons and steels used are given in the following table:

Material.	C. Per cent.	Si. Per cent.	Mn. Per cent.	P. Per cent.	S. Per cent.	Cu. Per cent.
Kahlbaum electrolytic iron	...	...	...	...	...	...
Electrolytic iron	...	...	...	...	...	...
Armco ingot iron	0·04	trace	0·21	0·005	0·029	0·042
Domnarvet "0·10"	0·05	0·005	0·44	0·045	0·020	...
Kohlswa steel	0·10	0·014	0·03	0·026	0·007	...
Fagersta A3442	0·16	0·009	0·32	0·024	0·012	...
Fagersta C2067	0·23	0·019	0·43	0·028	0·012	...
Fagersta D3136	0·33	0·047	0·41	0·028	0·012	...
Fagersta B2924	0·38	0·079	0·42	0·028	0·013	...
Hagfors No. 1, "0·60"	0·75	0·19	0·41	0·029	0·002	...
Hagfors No. 2, "0·90"	1·00	0·19	0·37	0·026	0·005	...
Hagfors No. 3, "1·20"	1·25	0·20	0·10	0·025	0·005	...

The specimens were in the form of cylinders 10 millimetres long by 1 millimetre in diameter. The dimension-ratio, therefore, was 10.

Although the external field had a strength of 15 gauss, the absolute field within the specimen was a very weak one, owing to the considerable demagnetising influence of the induced poles.* This influence being difficult to evaluate sufficiently well, it can only be stated that the internal field used is to be considered as being only a small fraction of 1 gauss.

* The value of the "demagnetising factor" in the well-known equation:

$$H_a = H_{obs.} - NI$$

is given by C. R. Mann (*Inaug. Diss.*, Berlin, 1895, p. 31) as N = 0·26 for specimens with the above-mentioned dimension-ratio.

6. Discussion of Results.

Three main series of experiments were carried out as follows :

(1) With steels, &c., annealed at 910° C.
(2) With steels, &c., quenched from 910° C.
(3) With steels, &c., quenched from 910° C. and reheated to about 500° C.

Nearly one hundred registrations were successively carried out, and some typical results are reproduced by careful tracings

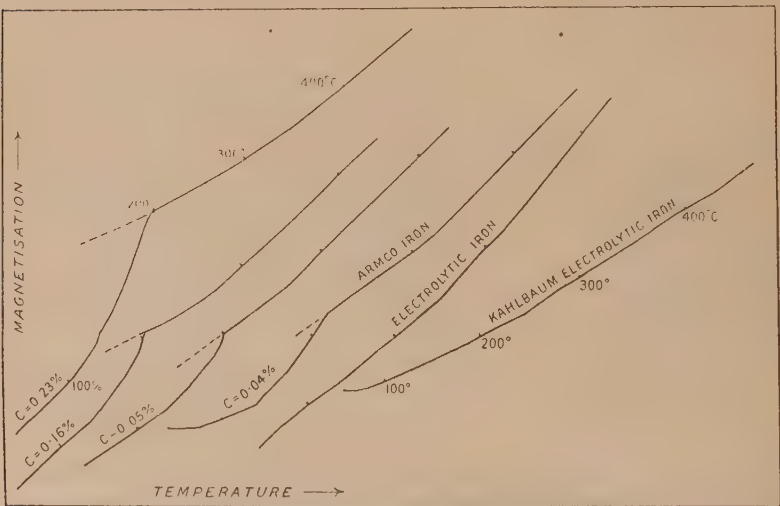

Fig. 5.—Steels, &c., Annealed at 910° C.

in Figs. 5 to 11. Some photographic reproductions are given in Figs. 12 to 15, Plate XLVIII.

For the curves shown in Fig. 5 specimens of two German electrolytic irons (one from Kahlbaum), an " Armco " iron, and three low-carbon steels, containing 0·05 per cent., 0·16 per cent., and 0·23 per cent. carbon respectively, were previously annealed *in vacuo* at 910° C. The curves for the electrolytic irons all show an angular point at about 250° C., the change being in the direction of increased magnetisation. Two curves from the Kahlbaum iron show the point at 245° C. and 255° C. respectively, while four other

curves from the ordinary electrolytic iron show it at about 250° C. In no case, however, is it very marked.

The curve for the electrolytic iron shown in Fig. 5 exhibits a change at about 120° C., but as this does not appear on the other curves for this material it cannot be considered here as authentic. In no case is anything to be seen at 200° C.

In the curve for "Armco" iron the effect of the introduction of carbon is at once seen; the curve passes through a very marked angular point at 215° C. If the amount of carbon present (0·04 per cent.) and the magnitude of the peak in the curve be compared, an idea of the sensitiveness of the apparatus for detecting small magnetic changes is obtained. A low-temperature point at about 130° C. makes its appearance in this curve.

The three low-carbon steels give the cementite point almost exactly at 200° C. One curve was obtained for the 0·05 per cent. carbon steel, and two for each of the others. The former gives a doubtful point at 265° C. The low-temperature point seen in the "Armco" iron appears again. For the 0·05 per cent. steel it is at 115° C.; for the 0·16 per cent. steel it occurs at about 130° C.; while for the 0·23 per cent. steel the temperatures given by two curves are near 130° C. also.

Thus this short series of registrations shows that in low-carbon steels, besides the very considerable magnetic change occurring near 200° C., there is another much smaller one taking place at about 130° C.

To investigate the effect of quenching, ten specimens of varying compositions were quenched in water from 910° C. Curves were obtained as before, but their nature had completely changed, as may be seen from Figs. 6 and 7.

On two curves obtained, the Kahlbaum electrolytic iron shows two angular changes, both changes resulting in an increase in the magnetisation. In both curves the points appear at 225° C. and 345° C. very nearly. The "Armco" iron gave irregular results; one curve gives angular points at about 130°, 175°, 240°, and 330° C., while a second gives points near 110°, 275°, and 375° C. No explanation of the variability of this material can be offered; it appears probable, however, that the points at 130° and 110° C., and at 240° and 275° C., are, respectively, one and the same.

The 0·10 per cent. steel gave a curve showing a somewhat

ill-defined bend at about 325° C., and two weak angular points at about 120° C. and 215° C. This latter point is presumably due to the presence of free carbide, showing that the quenching was not perfect.

The curves for the steels of compositions varying from 0·16 per

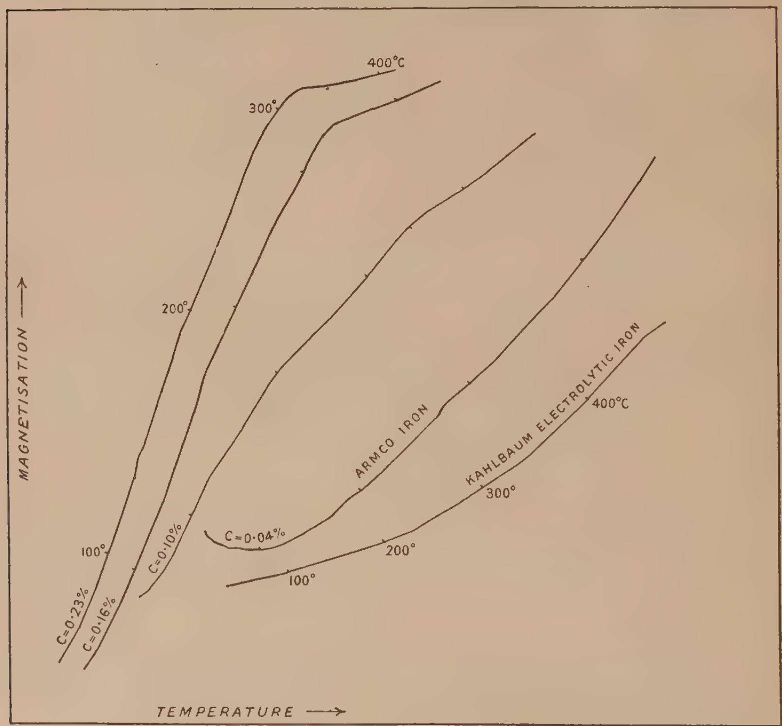

FIG. 6.—Steels, &c., Quenched from 910° C.

cent. to 1·25 per cent. carbon are all of the same type. The cementite point is either entirely absent or just faintly visible, and there also appears a very marked bending off at about 330° C. This point was previously observed at 300° C. by Dejean. The curves practically all agree in showing a change at 260° C. It is only a slight effect, and is consequently somewhat difficult to observe, but there appears to be no doubt as to its existence. A third change is also visible in most of the curves in the

neighbourhood of 120° C.; it generally appears as a weak angular point.

In the magnetisation-temperature curves of quenched steels, therefore, there appear to be three change points, namely, at or about 120° C. (very faint), 260° C., and 330° C.

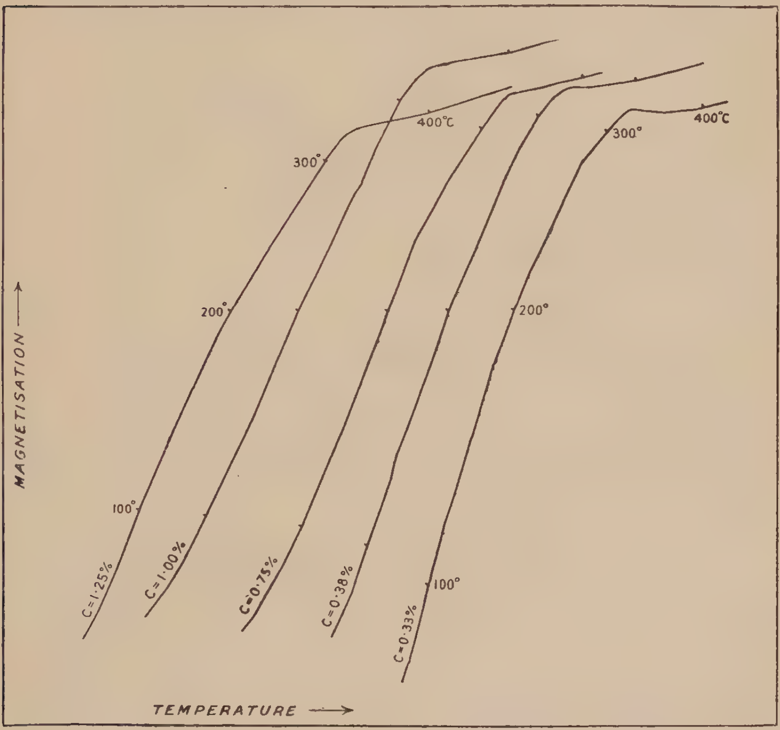

FIG. 7.—Steels, Quenched from 910° C.

Each quenched specimen having been heated to about 500° C. in the course of a registration, the experiment was repeated without changing the photographic paper, to show the effect of this heating of the hardened specimen by a curve strictly comparable with that given by the hardened steel. As might be expected, the curves for the steels hardened and then reheated to 500° C. are strikingly similar to those for annealed steels (Figs. 8 and 9). The change at about 215° C. appears in full strength, and there is absolutely

no trace of any bending in the curves at 330° C. All the curves show a weak angular point between 130° and 140° C., but the one at 260° C., observed in hardened steels, is not visible.

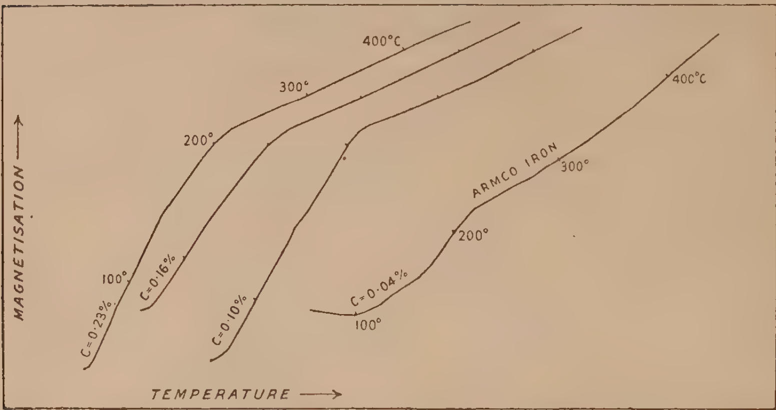

FIG. 8.—Steels, &c., Quenched from 910° C., Reheated to 500° C.

Curves were obtained for steels quenched from 910° C. and reheated to only 200° C. That due to a 1·00 per cent. carbon steel

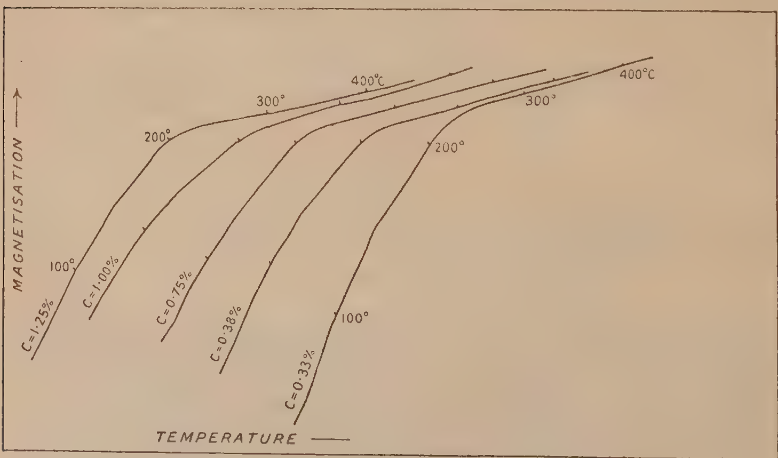

FIG. 9.—Steels, Quenched from 910° C., Reheated to 500° C.

(Fig. 10) shows a weak angular point at 120° C., a more marked one at 260° C., and finally the very large bending off at 330° C.,

indicating a decided loss in magnetisation. In the similar case of a 0·75 per cent. carbon steel a point occurs at 150° C., and the change at about 210° C. is just appearing. The point near 260° C., however, cannot be distinguished with certainty. A loss

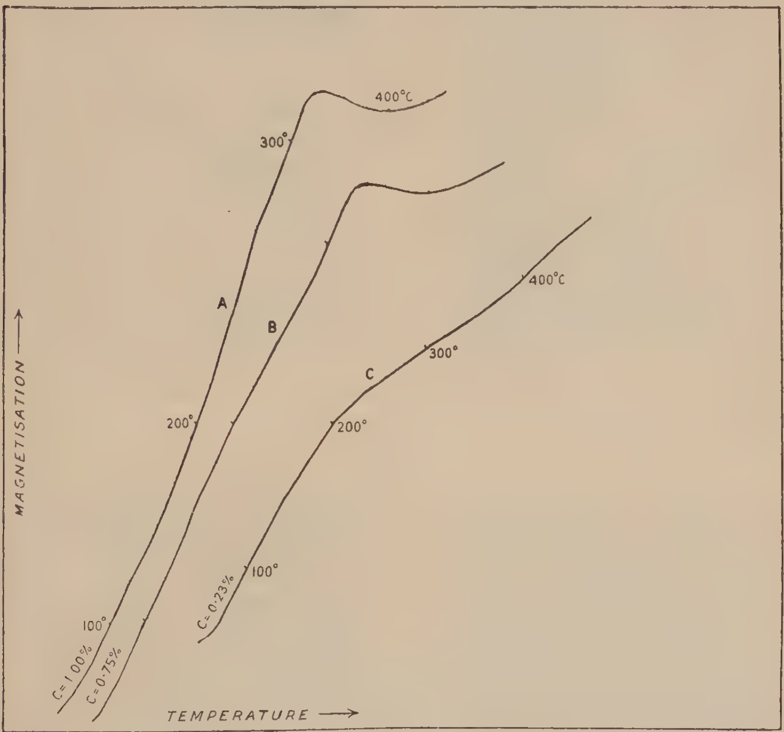

FIG. 10.

A. Quenched from 910° C., reheated to 200° C.
B. ,, ,, 910° C., ,, ,, 250° C.
C. ,, ,, 910° C., ,, ,, 350° C.

in magnetisation occurs, as before, at 330° C. The curve is also given for a steel containing 0·23 per cent. carbon quenched from 910° C. and reheated to 350° C.; there is here no trace of a change at 330° C. or at 260° C.

Figs. 12 to 15, as already mentioned, are photographic reproductions of some of the curves obtained :

Fig. 12.—Two curves given by annealed steel (1·25 per cent. carbon).

Fig. 13.—Curve I. Steel (0·38 per cent. carbon) quenched in water from 910° C. Curve II. Obtained immediately after I., showing the effect on the quenched steel of tempering at 500° C.

Fig. 14.—Curve given by steel (1·00 per cent. carbon) quenched from 910° C. and tempered at 200° C.

Fig. 15.—Explained below.

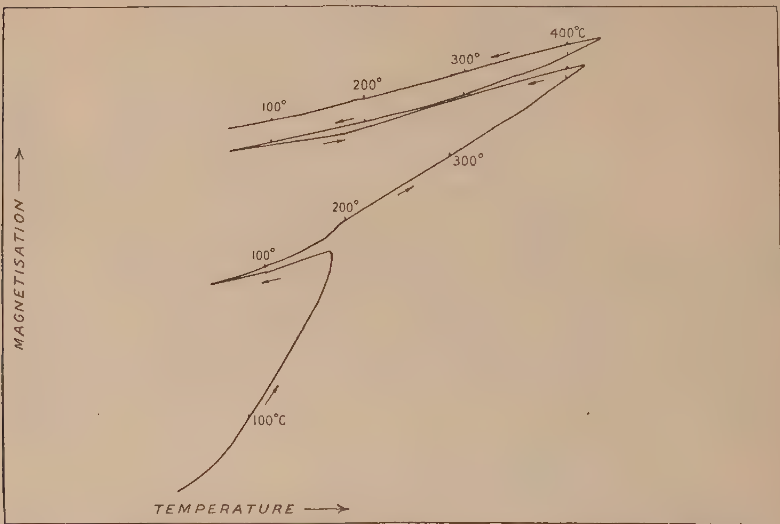

Fig. 11.—Successive Heatings and Coolings of Annealed Steel ($C = 0 \cdot 10$ per cent.) in Constant Magnetic Field.

So far as the actual curves obtained are concerned, for temperatures up to 400° C. and in a constant external magnetic field of 15 gauss, the results are as follows:

(1) Annealed or tempered carbon steels show two magnetic changes—one at 210° C., and the other at about 130° C.

(2) Quenched steels show three such changes, namely, at about 120°, 260°, and 330° C., the latter being very pronounced.

(3) Annealed electrolytic iron shows a point at 250° C.

(4) Quenched electrolytic iron shows two changes, at 225° C. and 345° C. respectively.

Reduced from 18×24 cm.

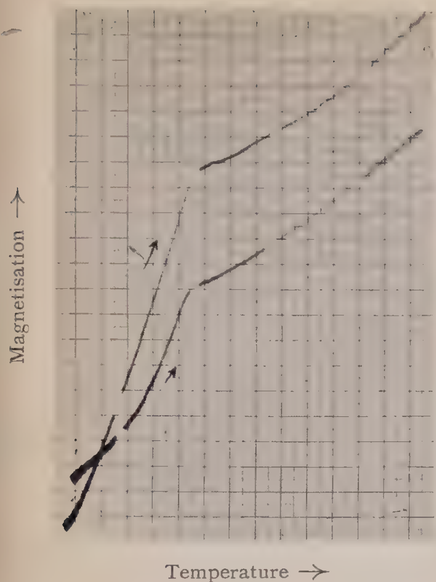

FIG. 12.

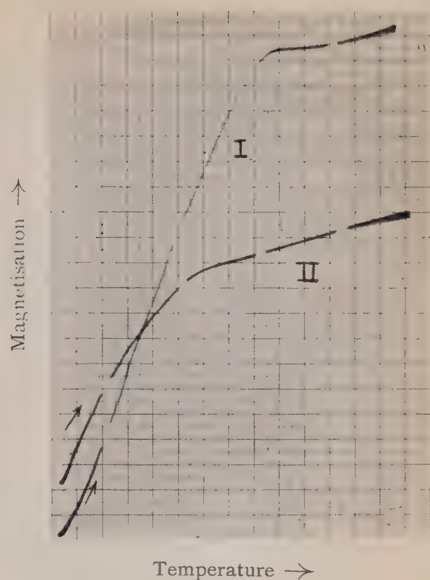

FIG. 13.

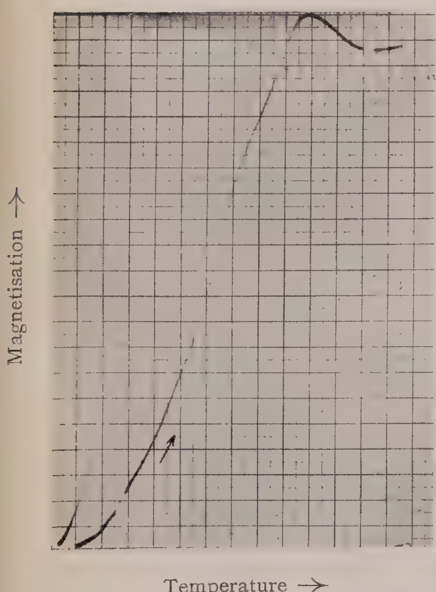

FIG. 14.

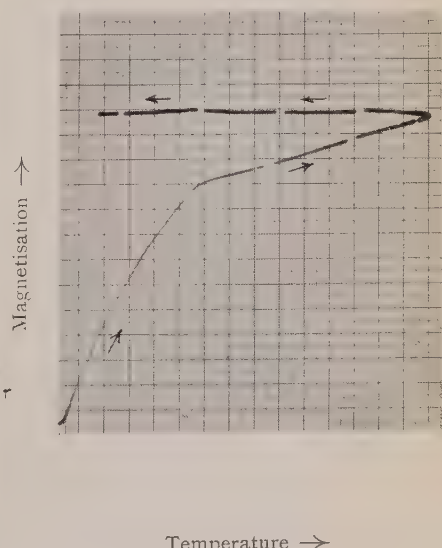

FIG. 15.

[*To face p.* 410

It will be seen at once that, magnetically, it has not been possible, so far, to obtain any confirmation of the supposed existence, in one and the same specimen, of a large number of periodically distributed transformation points (" Z-changes "). On the other hand, the existence of a few magnetic changes has been established, and the meaning of these will now be discussed.

Consideration of the change which occurs at 210° C. brings forth the following facts :

(1) It is not observed in electrolytic iron.
(2) It becomes more and more pronounced as the carbon percentage in the steel rises.
(3) It is not to be observed in fully hardened steels.
(4) Tempering the hardened steels restores the change to its full magnitude.

There appears to be no room for doubt that the change is due to the cementite present in the steel. Wologdine,[9] who discovered the magnetic change in cementite, expressed the view that at this point cementite becomes almost paramagnetic ; a similar opinion is held by Honda,[6] and also by S. W. J. Smith.[5] The present curves, however, can scarcely be interpreted in any other way than that the magnetisation of cementite possesses a pronounced singular point (probably a maximum) at this temperature (210° C.), with a decrease in the rate of magnetisation with temperature.

The explanation of the curves obtained by the present method appears to be as follows. As the temperature rises, the magnetisation of the steel increases rapidly, owing to the combined effect of a slow rise in the magnetisation of the ferrite, together with a rapid rise in that of the cementite. At about 210° C. the cementite attains its maximum magnetisation, the curve, therefore, becoming less steeply inclined to the temperature axis. After passing 210° C. the magnetisation of the carbide begins to decrease slowly, but at the same time that of the ferrite increases rather more rapidly than before, so that the curve still tends in the direction of increasing magnetisation.

Although this work was chiefly concerned with the study of temperature-magnetisation curves with rising temperature, one or two cooling curves were also registered. The cooling curve was

not simply the reverse of the heating curve, but showed a remarkable thermal hysteresis effect. The specimen lost but little magnetism as it cooled, and also the cementite point at about 210° C. was very much less prominent than on the heating curve. Fig. 15 shows the heating and cooling curve of a 1·25 per cent. carbon steel, which had been previously quenched from 910° C. and reheated to 500° C. In this case the temperatures marked on the two parts of the curve do not quite coincide. (This was subsequently traced to incorrect adjustment of the apparatus.) The chief point to notice, however, is that the magnetisation remains nearly constant as the specimen cools, and that the cementite point on this part of the curve is quite small.

Fig. 11, recorded in the early stages of the work, before vibration troubles had been properly overcome, represents the successive heatings and coolings of an annealed specimen containing 0·10 per cent. carbon. The order of the experiment was: Heat to 195° C. and cool to 50° C.; heat to 415° C., cool to 50° C.; heat to 425° C. and cool to 50° C. The curve suffers slightly from external vibrations and is useless for detecting small changes, but the point at 210° C. is clear on each heating curve—except, of course, on the first, which just approaches it—and it is not at all obvious on the cooling curves. The hysteresis effect mentioned above is again evident. The effect has been previously observed to some extent by Honda, and may be noticed in curves published by him and his collaborators.[6, 10, 11]

The significance of the change occurring in annealed and tempered steels at about 130° C. is obscure. There is but little reason to suppose that it has any direct connection with the point at 120° C., found in quenched steels, and which can be reasonably well explained. Pending a satisfactory hypothesis, it should be noted that abnormalities have already been found near this temperature by other workers. Robin [16] found a minimum in the sonority of steel at 120° C., while Lea [17] noted a discontinuity in the torsional rigidity modulus at that temperature. Thompson and Goffey [3] observed a change in the electrical resistivity, and also a striking minimum in the torsional elastic limit, at 120° C.; magnetic change points have been found at 150° C. by Morris, and at 135° C. by Roget. Hardness determinations have also indicated the existence of this critical point.

The points at 120° C. and 260° C., here found magnetically to occur in quenched steels, evidently correspond to changes already observed at these temperatures by other investigators. In 1896 Svedelius [12] found, on reheating quenched carbon steel (0·7 to 0·9 per cent. carbon), two well-marked change points, which he designated d_1 and d_2, at which contraction took place. At lower carbon contents only the upper point seemed to occur. The positions of d_1 and d_2 were more exactly determined by Charpy and Grenet [13] for a 1·2 per cent. carbon steel: d_1 began at 125° C. and extended to 170° C., with a linear contraction of 0·06 per cent.; d_2 began at 310° C. and extended to 350° C., with a contraction of 0·11 per cent. On lower carbon steels the upper point was predominant, as found by Svedelius.

In a detailed study of the quenched and tempered structures of carbon steels Enlund [14] proved two critical points to exist: a lower one at about 110° C., corresponding to the breakdown of martensite to troostite, and a higher one near 260° C., corresponding to the austenite-martensite (and troostite) transformation. These points were specially clear on electrical resistance curves.

If it be correct that the point found on the magnetisation curves at 120° C. corresponds to the transition of martensite into troostite, then it may be asked why, on continuing the heating, the carbide change at 210° C. is not observed, as would be expected if there were free cementite in the steel? There are apparently only the two following possibilities: either martensite does not actually break down into troostite at 120° C., or it does break down into troostite, but the latter contains no "magnetically free" carbide, that is, the carbide particles are still too small to have any sensible magnetic action.

The first possibility can probably be ruled out, as several good reasons are at hand in support of Enlund's view, so the second seems at present to be the only one acceptable. This view, to some extent, might account for the remarkable decrease in magnetisation which has been found to occur at 330° C., and which otherwise remains unexplained; as a matter of fact, if at this temperature the cementite particles attain so large a size as to possess the proper magnetic character of cementite, the formation of the "magnetically free" cementite, on account of its lower

permeability, will signify a decrease. Before accepting this view, however, a more detailed study is necessary.

It may be added that Movius and Scott [15] carefully investigated the heat evolution which takes place on reheating quenched steels. They found a well-marked evolution ending at about 300° C.; the range over which the phenomenon took place was raised as the rate of heating increased. For so-called "zero rate" they considered that the change started at about 135°, attained a maximum near 250°, and ended at 260° C. For a rate of heating as used in these experiments the respective temperatures are approximately 190°, 300°, and 330° C. This supposition that a continuous change takes place on reheating quenched steel might appear to be contrary to the results of the present magnetic work, in which three distinct changes are to be detected, but the possibility is not excluded that, by using a less sensitive method, the whole change might appear to be but one process.

The curves given by the quenched and annealed specimens of the electrolytic irons are totally different from those of the carbon steels. The annealed specimens showed a sudden increase in magnetisation at about 250° C., while the quenched materials showed two similar changes at 225° and 345° C. respectively. Repeated experiments with these materials always gave the same results, but it is not possible at present to offer a reasonable suggestion as to the nature of these changes, or what effect they may have on the shapes of the curves.

7. Summary.

This report describes an investigation on the low-temperature changes in iron and steel by a magnetometric method in which the specimens were heated while suspended at an angle of 45° to a constant magnetic field of 15 gauss. The corrected field was estimated to have a value of only a small fraction of 1 gauss. The apparatus was devised to register photographically temperature-magnetisation curves. It was considerably complicated by the means adopted to eliminate vibration.

Cylindrical specimens 10 millimetres long and 1 millimetre in diameter were used; their composition varied from pure electro-

lytic iron up to 1·25 per cent. carbon steel, and they gave the following results:

1. All curves used are heating curves. Those registered on cooling, even in the case of annealed specimens, differ very considerably from the heating curves, in that they show a much higher magnetisation. This phenomenon of "thermo-magnetic hysteresis" has, to some extent, already been observed by Honda.

2. In spite of the sensitivity of the apparatus used, it was not possible to detect magnetically any supposed periodical "Z-changes" occurring in a given iron or steel specimen on increasing the temperature.

3. The only points detected in carbon steel when annealed at 910° C. (or tempered at 500° C.) were a very weak point at about 130° C., corresponding to an increased magnetisation, and a change at 210° C., in the direction of lowered magnetisation, the latter apparently coinciding with the cementite point discovered by Wologdine.

4. Steels quenched from 910° C. showed two very weak changes at 120° C. and 260° C. respectively, and a bending off in the curve at 330° C., indicating loss of magnetisation.

5. Annealed electrolytic iron was found to show one change at 250° C.; the quenched material exhibited two, at 225° and 345° C.

This paper represents the report presented by the first Hadfield Research Scholar at the Metallographic Institute, Stockholm, where the work was carried out.

One of the authors (W. H. D.) wishes to express his very sincere gratitude for the kind and willing assistance rendered by the Staff of the Institute, and most particularly by Mr. J. Härdén.

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Iron and Steel Institute.

DEFORMATION LINES IN LARGE AND SMALL CRYSTALS OF FERRITE.*

By HUGH O'NEILL, M.Met., M.Sc. (University of Manchester).

Introduction.

In 1898 Stead [1] showed that ferrite cleaved along the cube face, and this was confirmed by Osmond, Frémont, and Cartaud,[2] and later by Osmond and Frémont [3] in the course of their study of the mechanical properties of large single crystals. Ewing and Rosenhain [4] found that slip-bands in ferrite ran along the diagonals of the cube etch pits, and were sometimes parallel to the sides of the cube. The inference was made that iron slips along octahedral (111) planes, and sometimes also along the cube (001) faces. The pressure silhouettes obtained by Osmond and Cartaud [5] on the cube face of α-iron could be resolved into lines of slip parallel to the diagonals of the cube, and they concluded that the (111) plane was involved. Howe,[6] after a careful consideration of all the evidence obtained by Ewing and Rosenhain, and Osmond and Cartaud, interpreted their results as showing that α-iron slips along the icositetrahedral (112) planes. Recent X-ray studies of deformation have led Polanyi and others [7] to believe that in iron rhombicdodecahedral (011) movement is involved, the direction of gliding along this plane being (111) according to Weissenberg,[8] or possibly (112) according to Mark.[9] The author pointed out in discussing a paper by Edwards and Pfeil [15] that their fracture fragments were consistent with both (100) and (011) failure, and a review of existing evidence by Thompson and Millington [10] led them to favour these two planes.

In a recent paper [11] the author studied the effect of deformation upon the density of large single crystals of vacuum-melted electrolytic iron containing 1·8 per cent. of silicon. In both tensile and compression tests, with the stress applied along a

* Received January 28, 1926.

quaternary axis, certain slip-band markings were observed to run at 45° to that axis. Movement along a (001) plane cannot give this result, and the conclusion was therefore inferred that (011) gliding was involved, in agreement with the X-ray evidence. Further work of a metallographic nature has since been carried out on the crystal deformed in tension, and the results require a modification of this conclusion. Everything now goes to show that slip proceeds along (112) planes. Extensometer readings taken during the tensile test indicated an elastic limit of not more than 0·9 ton per square inch, and the density of the crystals did not fall as a result of severe deformation.

The Lattice Structure of Silicon Iron.

A crystal of iron containing 3·5 per cent. silicon examined by Hull [12] on the Bragg spectrometer gave atomic spacings corresponding with those obtained from an aggregate of pure iron tested by the Hull method. Dr. A. J. Bradley, of the Department of Physics of the University of Manchester, kindly undertook an X-ray examination of a filament of the silicon iron used by the author. The X-ray spectrum (Fig. 7, Plate XLIX.) showed that it was body-centred cubic like α-iron, and consequently the presence of 1·8 per cent. of silicon in solid solution should not cause the fundamental mode of deformation to differ from that of the pure metal.

The Fracture Wedge of the Single Crystal.

Reference must be made to the previous paper [11] for details of the conditions of test. Two crystals were deformed, one in compression and the other in tension. In both cases the stress was applied along a quaternary axis, the orientation of the grains being initially determined by "pressure figures." In this way the original condition of the material was maintained; it was neither etched nor annealed, but represented virgin metal. Fourteen months after fracture one-half of the tensile crystal was carefully sectioned along its stress axis by means of a hack-saw, the plane of section being at right angles to the edge of the fracture wedge (see Fig. 1, *a*). It was carefully ground flat on

a fine stone, photographed (Fig. 8, Plate XLIX.), and then polished and etched in 2 per cent. alcoholic nitric acid. A macrostructure soon appeared, but etching was continued for about thirty minutes in order to develop the very strange microstructures visible on the plane of section. Fig. 2 shows diagrammatically the more interesting regions of the specimen based on microscopic examination and photomicrography.

Macroscopically, two zones, *A* and *B*, could be seen on the

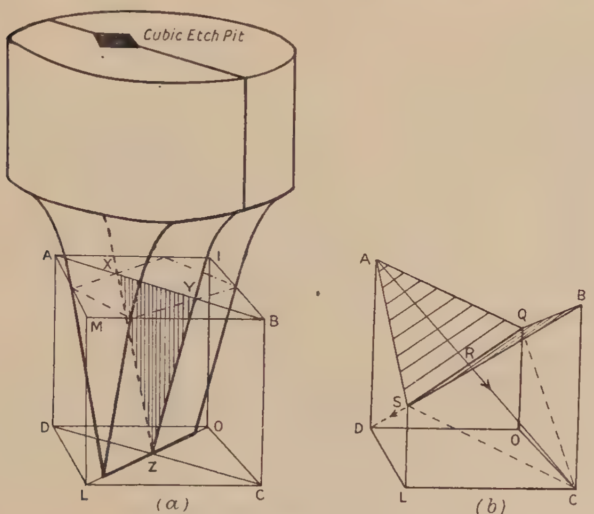

FIG. 1.

section, one on each side of the axis. The zones were approximately triangular, with their apices upwards and in contact with the edges of the base of the fracture wedge. They met and overlapped in a region of very confused distortion *C*, made evident by the folds and furrows visible to the naked eye on the etched surface. Fig. 9 is a photomicrograph taken in this "twisted" region, and under higher powers the black curved lines resolve into striated furrows. The region of actual fracture (Fig. 10) suggested its having undergone a twisting or wrenching motion, and two fissures parallel to the top surface of the test-piece were also found in the lowest part of the specimen, Fig. 11. Although axial loading shackles were employed, the wedge was not entirely

symmetrical with the head of the test-piece, but owing probably

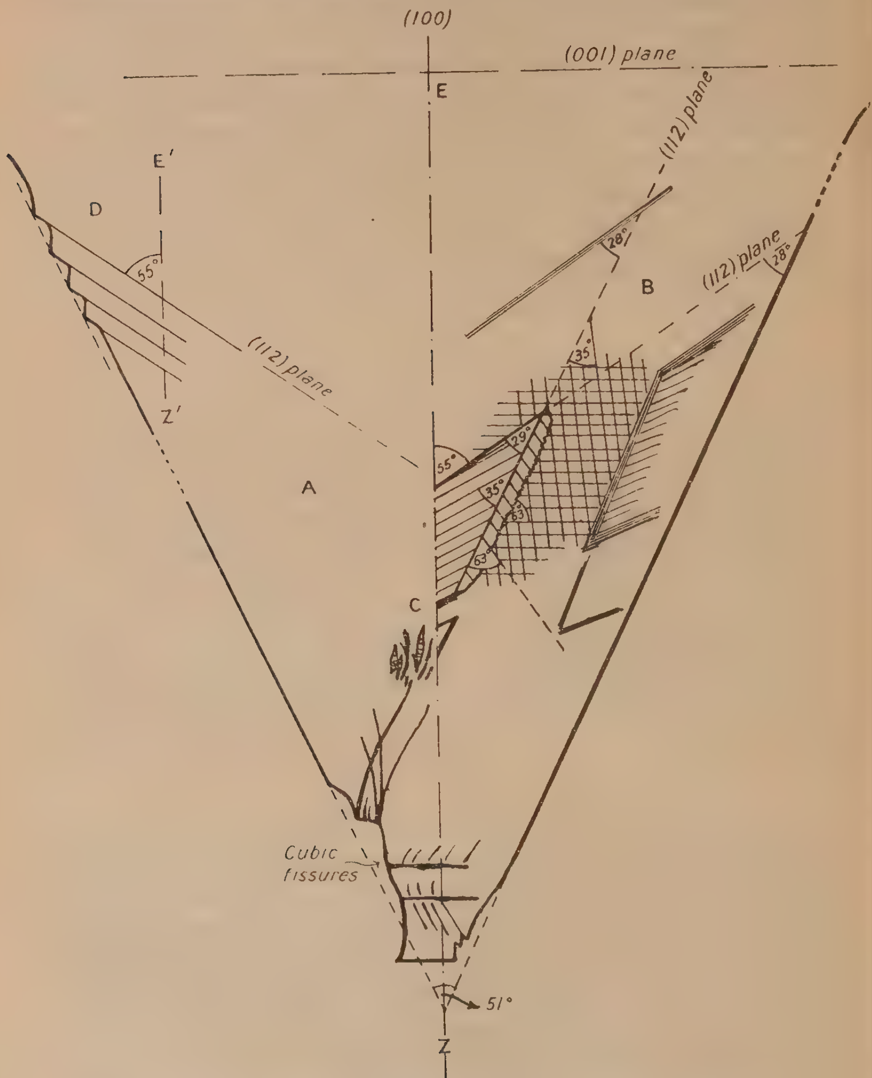

Fig. 2.—Sectional Wedge (Diagrammatic) showing Angles (corrected) between Etch Markings.

to the lack of perfect alignment between the stress direction and

the quaternary axis, it pulled out more on the left-hand side than on the right. This appears to have caused the formation of a stepped surface on the left side, which is represented in section in region D, Fig. 2. Fig. 12 (Plate L.) is a photomicrograph of this region in the unetched condition, whilst Fig. 13 was taken after etching. It is evident that the appearance here is due to block slipping upon a series of parallel planes, whose orientation was next determined.

Determination of Planes of Slip.

Three independent observers were given photographs of the sectioned wedge, and they reported the included angle XZY (Fig. 1, a) between the straight sides as 52°. This means that the central quaternary axis is inclined at 26° (approx.) to the sides. A mean line was drawn through the points of the serrations in Fig. 12 as being parallel to the side of the wedge, and at 26° to this line another one, $E'Z'$ (Fig. 2), was drawn representing its axis. The lower edges of the steps were then produced inwards until they intersected $E'Z'$, and the angles made therewith were measured. The average of the measurements save one gave the angle θ' of slip plane traces to the quaternary axis as 56° (approx.).

Before proceeding further it was necessary to determine the orientation of the plane of section. This was done by polishing the flat head of the test-piece and etching with 2 per cent. alcoholic nitric acid so as to produce etch pits. Cubic pits were obtained (see Fig. 14, Plate L.), thus confirming the pressure figure observations as to the original orientation of the crystal. In consideration of recent work by Dr. Elam,[13] no doubt is left that the top surface of the specimen was practically a (001) face. The top edge of the plane of section XYZ was found to be nearly parallel to one diagonal of any etch pit, and from the theory of these latter * it follows that the plane of section was a rhombicdodecahedral (011) plane. This is represented in Fig. 1, a, where XYZ is made to lie in the rhombicdodecahedral plane $ABCD$. The sectioning had originally been done at right angles to the edge of the wedge by eye judgment, but by measurements made on the metallographic camera there was found to be

* See "Mineralogy" (Miers), p. 114.

a divergence of 13° from the true (011) position. Consequently angular measurements made on the surface of the plane of section must be corrected trigonometrically to correspond with readings on the (011).

Consequently $\tan \theta = \tan \theta' \cos 13°$;
$\therefore \quad \theta$ = angle of trace of slip plane on (011) to quaternary axis = 55°,
and ϕ = angle of wedge = 51°.

The application of this result to the possible planes of slip which will agree with all the experimental evidence may now be considered. According to Jeffries and Archer and others, a wedge forms when a single crystal is fractured, owing to successive minute slips along conjugate crystallographic planes. Thus, if in Fig. 3 *ABCD* is a plane of section through the axis *EZ* along which the single crystal is being stressed, then slip commences along the most favourably situated plane, whose direction may be taken as *AC*. It is found experimentally that slip on this plane soon ceases, and as the symmetry of the system has been disturbed movement next takes place along the conjugate slip plane, opposite to the former, and in the direction *BD*. A succession of equal slips along alternate conjugate slip planes results in an extension of the crystal, and at the same time in a reduction of its diameter in a plane perpendicular to the slip planes. Thus a wedge is eventually formed, although the production of a pyramid or a cone does not seem impossible if another pair of conjugate slip planes is available at 90° to the first. Two pairs of planes are generally so available, and an explanation of the general absence of pyramidal fractures may be that *one* slip plane always happens to be more favourably situated for gliding than any other, and movement originates along it. This movement can then be compensated for solely by slip along the *conjugate* plane, and the other set is not called into action. Further, if θ be the angle made by the slip plane to the axis, then, according to Goucher,[14] the angle ϕ of the wedge formed is given by

$$\tan \frac{\phi}{2} = \frac{1}{2} \tan \theta.$$

Suppose, now, that the crystal under examination has slipped along conjugate (011) planes, as was first believed. These are inclined at 45° to a quaternary axis (*e.g.* planes *AMCO* and *IBLD*,

Fig. 1, a), and it is obvious that a wedge would be produced whose edge would be parallel to a cube face. But actually the edge was

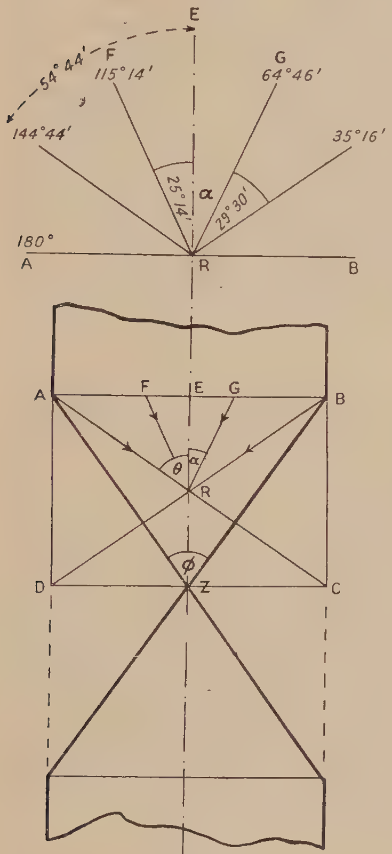

Fig. 3.

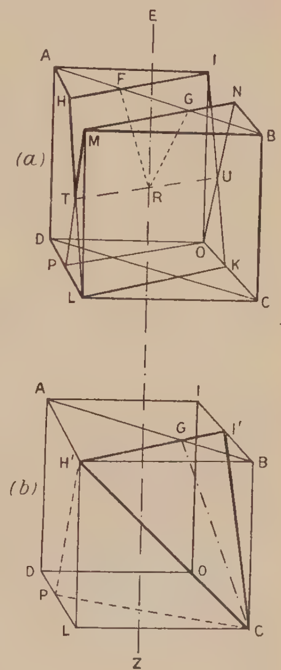

Fig. 4.

parallel to a (011) face (see Fig. 1, a), and hence the theory of (011) slipping must be discarded.

Consider next the octahedral (111) planes. Their traces run in three directions along a (011) face, such as the one which has been examined. The trace angles made by conjugate (111) planes with the vertical axis are 35° 16′ and 90°. Movement along the former would give a correctly orientated wedge, but the

experimental result of $\theta = 55°$ does not agree with this plane, and consequently (111) movement must be rejected.

The next likely plane to be considered is that of the (112), whose traces on a (011) face run in five directions, as shown in Fig. 3. Conjugate (112) traces make angles with the quaternary axis of 25° 14′, 54° 44′, and 90°, and the two former should give fracture wedges of 26° 32′ and 70° 32′ respectively, if Goucher's expression is general. The experimental result of $\theta = 55°$ agrees well with the angle made by the second set of (112) planes, and shows that (112) movement has taken place. The actual wedge angle of 51° is not in agreement with that calculated, but being a mean of the two possible angles suggests movement along both pairs of (112) planes. This point will be considered later.

It is important to note that in a single crystal of body-centred tungsten Goucher [14] found that the (112) was the normal plane of slip. Whilst his crystal had been produced by the method of straining and annealing, that of the author was in the "as cast" condition, and therefore fully represents a large grain of normal metal.

It is necessary to correlate the (112) movement here advanced by the author with all the previous evidence of slip in a direction making 45° with the edge of a cube face. Hitherto this evidence has been interpreted as indicating (111) or (011) movement. However, it can be shown to apply equally to slip along the (112). In Fig. 4, *b*, planes $H'I'C$ and $PH'C$ are both (112) planes whose trace $H'C$ on the face of the cube makes an angle of 45° with the edge of the cube. The (112) movement is therefore in agreement with all these observations.

The Probability of Duplex Conjugate (112) Slip.

It has been shown that gliding has taken place along (112) planes, making trace angles (ERB) of 54° 44′ with the axis. These are represented in Fig. 1, *b*, by planes $AQCS$ and $BQDS$ intersecting along SRQ and giving a wedge parallel to SRQ. The conjugate (112) planes making a trace angle ERG of 25° 14′ with the axis are shown in Fig. 4, *a*, as $HIKL$ and $MNOP$ intersecting along TRU and making a wedge parallel to TRU. Now, it will be seen that

TRU is not parallel to *SRQ* (Fig. 1, *b*), but that both pairs of (112) planes are favourably situated for slip to proceed. Hence if what might be called duplex conjugate slip occurs, the effect can be imagined as an attempt on the part of the crystal to produce simultaneously two wedges intersecting each other at an angle (*HIM*) of 18° 26′. The author believes that this double slipping has taken place, as it helps to explain the following observations:

(1) The wrenched appearance of the actual fracture.
(2) The twisted and folded appearance of the zone *C* (p. 419).
(3) The diameter measurements made during straining, and reported on p. 106 of the previous paper.[11]
(4) (112) planes giving the previously observed 45° traces on a cube face make an angle *GCB* (Fig. 4, *b*) of 25° 14′ with the quaternary axis.
(5) The important microstructures in zone *B* (Fig. 2) which suggest movement along two planes inclined at 26° and 55° approximately to the vertical axis.

The appearance of the interesting region in zone *B* is seen in Fig. 15 (Plate L.). It has the appearance of being stratified along two sets of intersecting planes, and measurements on the screen of the metallographic camera, and others taken from photomicrographs, show that these planes make angles of approximately 55° and 26° with the wedge axis. They therefore correspond to the two (112) directions mentioned before. Photomicrographs of the lozenge-shaped area are shown in Figs. 16 (Plate L.), 17 and 18 (Plate LI.), and the corrected angular directions of the planes and the etch markings are given in Fig. 2. Perhaps the most noteworthy feature visible in these photomicrographs is the lamella, which appears to be twinned with respect to the zone of material lying immediately to the right of it. This zone exhibits etch pit effects which are nearly squares, and the lamella in many ways resembles a Neumann band. Figs. 16 and 17 show a transitional or merging effect of the etch striations at the top end of the sectioned band, as though the twinned (?) plate were "running out." The whole section was subsequently rubbed on 000 emery-paper, and repolished and etched. Careful inspection of the specimen (Fig. 19) showed that the lamella had disappeared, indicating that it did not run right through the

crystal. This suggests that it is a "bar," formed by the intersection of two inclined slabs of slipped metal.

As Neumann bands are generally supposed to be produced by shock deformation alone, an attempt was made to develop them by static indentation of this material. The crystal wedge was mounted in Rose's metal, and impressions were made on the polished top (001) face. Fig. 20 (Plate LI.) shows the untouched surface round an indentation made with a 1-millimetre ball and 40-kilogrammes pressure, and by very careful illumination a surface

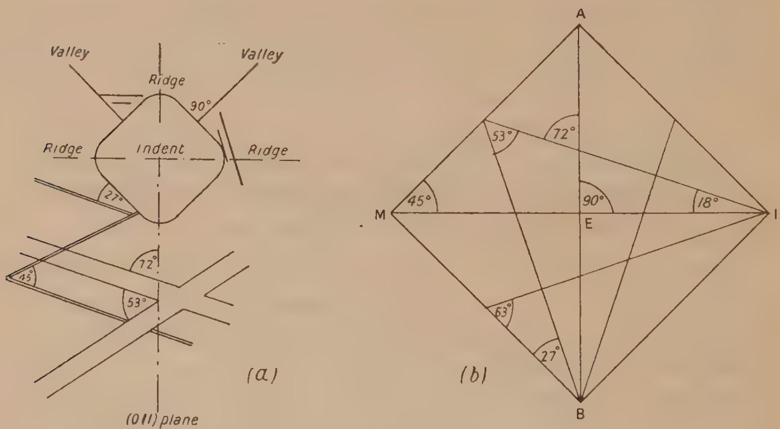

Fig. 5.

marking like a St. Andrew's cross was made visible. Slip-bands due to indentation run across this marking in an irregular manner, and the general orientation of the surface effects is recorded in Fig. 5, *a*, beside a diagram showing the traces of (112) planes along a cube face. The markings obviously correspond to (112) traces. Fig. 21 shows the area round an indentation after the "pressure figure" had been carefully polished off (commencing on 00 emery-paper) and the specimen etched for ten minutes in 2 per cent. alcoholic nitric acid. Large bands are visible near the indentations, but the background is traversed by numerous fine lines which at first sight appear to be scratches. The specimen was repolished and re-etched three times, and the "needle" markings reappeared on each occasion. Measurements of their

angles of intersection and their general appearance have convinced the author that these are not ordinary surface scratches, whilst the broad bands running in at least six directions appear to be Neumann lamellæ. Some of them are inclined to each other at angles of less than 10°—a phenomenon noticed also by Howe—for which no explanation is offered.

A recent photomicrograph by Moser [24] shows certain deformation lines round a Brinell impression made on the face of a single grain of silicon iron. If the markings be traced and the angles made by them with the side of his "square" impression be measured, they indicate in all cases that the lines are the traces of (112) planes. The production of lines along icositetrahedral planes by the static deformation of large silicon iron crystals is therefore fully confirmed.

The Cleavage of Ferrite—X-Ray Test.

In view of the fact that whilst proving cubic cleavage in ferrite, Osmond, Frémont, and Cartaud [2] found that in some instances it fractured along (112) planes, and further, that Howe [6] has observed both cube and (112) fractures, it was thought desirable to examine the cleavage faces of some coarse ferrite. A cleavage prism was excavated from a mass of mild steel crystals found in the fractured end of a piece of shafting kindly given by Professor F. C. Thompson. Three cleavage faces, practically at right angles to each other, could be observed in the specimen, and it was mounted on the Bragg X-ray spectrometer for examination. A good spectrum reflection was obtained from one of the faces at the chamber setting for the (001) plane, no reflection being detectable at 4° from that setting. At the setting for a (110) face only a minute deflection was observed, and this could scarcely be distinguished from scattering effects. Cubic cleavage was entirely confirmed, and it may be accepted that the straight fissures in the silicon iron crystal wedge (Fig. 11, Plate XLIX.) were due to cubic failure. Nevertheless the (112) fractures mentioned above must be noted, for a further detailed consideration of the cleavage fragments of crystals shown in Fig. 20 of Edwards and Pfeil's paper [15] shows cube cleavage, but such angles as 45°, 53°, 72°, and 90° can be found between the traces of the fracture

planes on the surface of the specimens. If these surfaces are cube faces (as their indentation evidence suggests), then some of the fracture lines must be the traces of (112) planes. The 45° angle previously led the author to suspect (011) cleavage.

Application of Density Measurements and Mechanical Test Results.

The amorphous metal hypothesis as applied to the deformation of metals suggests that crystalline packing is destroyed in the vicinity of gliding planes, and the density of the mass is slightly reduced in consequence. This explanation of the decrease of density found in crystalline aggregates should apply equally well to single crystals, since deformation of the former is due to movement within individual grains. Internal detrition should also occur in single crystals and give similar results. In the previous research [11] no such decrease was found, and the experimental evidence is therefore in disagreement with this aspect of the amorphous metal hypothesis.

An explanation of the decrease in density of a cold-worked, body-centred aggregate is still required. If (112) movement alone is the normal deformation in such cases, then the decrease of density may be referred to an " opening " of the atomic packing at the irregular crystal boundaries. Osmond, Frémont, and Cartaud [2] repeatedly observed irregular " slashed " edgings (*bordures*) festooned round the grains of ferrite which had been deformed in the cold. These " slashes " were parallel to the cubic cleavage planes. Reference has already been made [2, 4, 6] to the presence of markings related to both the (112) and the (100) planes in deformed aggregates, and it is suggested that the restrictions imposed by the grain boundaries cause the cubic cleavage planes to become involved. The arguments of Thompson and Millington [10] could now be applied, for cube-face movement was used by them to explain certain deformation features of fine aggregates not met with in single crystals—*e.g.* decrease of density, high elastic limit, and a well-marked yield.

In the body-centred cubic lattice the atom density is greatest on the (011) plane. A model may be constructed of similar spheres each of which represents unit spacing round an atom

situated at its centre. These spheres will need to touch each other in two directions in any (011) plane if the structure is to be built up. In any direction along which spheres do not touch there is obviously more than unit spacing, and therefore a greater distance over which attractive forces must act. Examination of such a

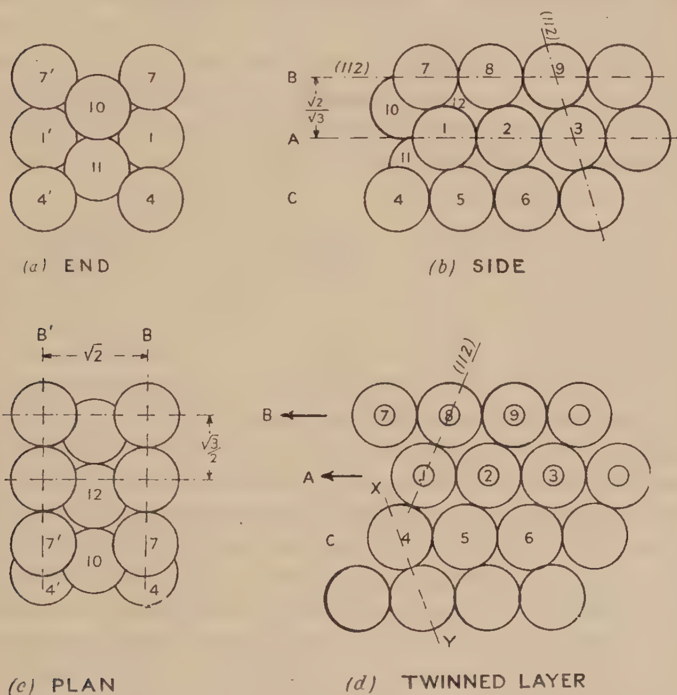

FIG. 6.

body-centred cubic model will reveal that in any one (112) plane the spacing spheres are arranged in parallel continuous straight strings lying one above the other, as shown in Fig. 6. (All the spheres have not been indicated in this diagram in order to keep it as simple as possible.) The side view (*b*) of the model represents an elevation of a (011) face (*vide* spheres 8, 3, 6, 1, 2), and it is evident from the spacing considerations that the atoms (*e.g.* at 1, 2, and 3) in the (112) plane *A* can move very easily over the atoms (*e.g.* at 4, 5, and 6) in the (112) plane *C*. The stress required

to commence such movement would appear to be very low, and is in agreement with the results for elastic limit obtained in mechanical tests. Furthermore, the density of the whole crystal would undergo no appreciable change as a result of this movement along (112) planes. In fact, if row A moves along so that the atoms at 2 and 3 occupy the positions previously held by 1 and 2, no change of density will occur. In the previous paper [11] it was shown that after deformation by tension or compression the experimental values for the density of single crystals did not decrease. This fact could not be explained by (110) movement, but is in agreement with slip along the (112) planes.

Production of Twin Lamellæ by (112) Movement.

Continuing the consideration of Fig. 6, if, owing to stress, atoms at 2, 3, &c., in row A move over row C a distance of $\frac{\sqrt{3}}{2}$ times the side a of the elementary cubic cell, then they will reach the positions previously occupied by 1, 2, &c., and the packing of these two rows will remain unchanged. If rows A, A', B, B', and the row containing spheres numbered 10, 12, &c., all move together over rows C, C', for this same distance or some simple multiple of it, then the packing of the crystal will remain unaltered. This " complete " movement along the (112) planes should produce slip-bands as surface escarpments in the way first suggested by Osmond and Cartaud,[5] and later worked out in detail by Thompson and Millington.[10] No well-defined etching effect would be expected in this case if the slip-bands be polished off, as there is no internal change of orientation.

Supposing, now, that the conditions of deformation are such that, instead of one or more " complete " movements along (112) planes, row A only moves a distance of $0 \cdot 577a$,* then the spheres at 2, 3, &c., come up against the right-hand side of the spheres at 5, 6, &c. Also if row B moves a similar distance (or some simple multiple of it) over row A, then rows A and B bear a new relation to row C and the unmoved portions of the crystal. They form a twinned slab in the grain, extending to a depth equal to the number of strings of atoms B, B^1, B^2, &c., which are involved in

* See correspondence, pp. 444, 445.

the movement. Since such a layer will lie in a (112) plane it corresponds (to that extent) to a Neumann band, and whilst it will produce a surface slip escarpment it will also give subcutaneous etching lines resembling the Neumann lamellæ. The etch traces of slip-bands (called X-bands by Howe) which are sometimes seen may be explained by the production of very thin twinned layers in this way. The lines visible in Fig. 13 (Plate L.) are examples of this phenomenon.

A cube contains twelve directions of (112) planes, and this comparatively large number, together with the particular arrangement of their atoms in the body-centred packing, is probably the reason why the crystals of iron glide along them. The three-dimensional consideration of all possible (112) movements for a given condition of stress is difficult to visualise, but the production of these twinned layers in the mass would seem to involve a certain internal distortion of the crystals. In fine aggregates boundary interference may so limit this distortion that Neumann bands do not readily form. Further, if duplex (112) movement takes place—that is, deformation along (112) planes inclined to each other (*e.g.* direction A and direction XY, Fig. 6)—then "intersection bars" will result, which may even contain a different order of packing. The lamella shown in Figs. 16, 17, and 18 (Plates L. and LI.) may be such a "bar." It is, however, clear, without further speculation, that simple gliding along the "handiest" (112) plane (or pair of planes) in ferrite can readily produce twinned layers of any thickness as measured in two directions at right angles.

Since arriving at this conclusion the author finds that Professor Thompson and Mr. Millington reached the same result early last year.

Further Consideration of Effects in Aggregates.

Dr. Rosenhain and Miss McMinn [16] have recently carried out some careful experiments on the relations between slip-bands and Neumann lines. The present author would apply their work in the following way:

(1) It was found that if ferrite containing Neumann lines were slowly compressed, the resulting slip-bands were in some cases parallel to the Neumann lines. Howe

found a similar parallelism. This evidence suggests (though it does not prove) that slip proceeds along the same planes as those in which Neumann lamellæ are to be found.

(2) Since Neumann lines in any one grain may cross each other, the observation that slip-bands sometimes cross an existing Neumann line does not contradict this suggestion.

(3) The absence of regularity in the crossing of Neumann lines by slip-bands is not surprising when slip-bands proceed through ferrite crystals themselves in an irregular manner. Curved and branched slip-bands may be due to movement in conjugate directions along the many (112) planes present, and if Neumann bands are twins there will be conjugate directions of slip within the Neumann band. It must always be remembered, however, that Osmond believed that certain types of slip-band were not related to any crystallographic system, and quite recently Taylor and Elam * came to the same sort of conclusion.

(4) If their tentative suggestion be accepted that Neumann lines are bundles of slip-bands, then the direction of slip would appear to be that of the direction of Neumann lines. Since it is known conclusively that Neumann lines occur along the (112) planes (together, in some cases, with certain bands along the (100)), there appears to be some justification for (112) slip in aggregates.

With the intention of obtaining more evidence, the author has experimented with a piece of coarse ferrite strip about $\frac{3}{32}$-inch thick. It was kindly given by Mr. Pfeil, and represented an unsuccessful attempt to obtain a single crystal of iron by the method of decarburising, straining, and annealing developed in collaboration with Professor Edwards. Small surface crystals had previously been filed off; a portion of the strip, sawn off in a vice, was rubbed down on emery, polished and etched in 2 per cent. alcoholic nitric acid. The grains were from $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter, and two of them gave square etch pits. The position

* See *Journal of the Iron and Steel Institute* 1924, No. 1, pp. 114, 115. Discussion on Thompson and Millington's paper.

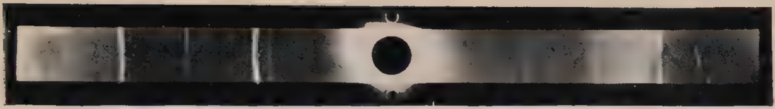

FIG. 7.

FIG. 8.—×5.

FIG. 9.—×100.

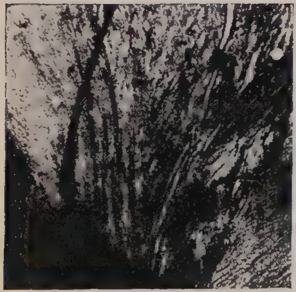

FIG. 10—×100.

FIG. 11.—×100.

NOTE.—Figs. 9–11 are reproduced half-size.

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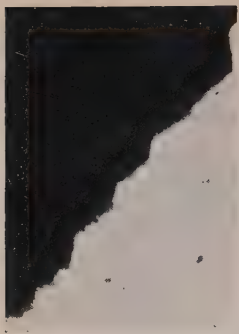

FIG. 12.—×200.

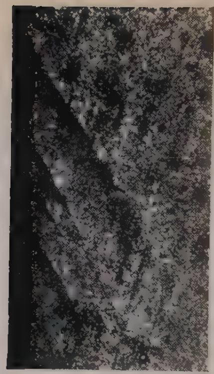

FIG. 13.—×200.

FIG. 14.—×450.

FIG. 15.—×90.

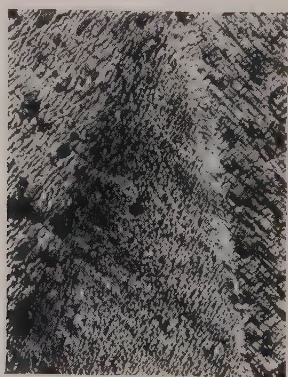

FIG. 16.—×500

NOTE.- Figs. 12–16 are reproduced half-size.

FIG. 17.—×500.

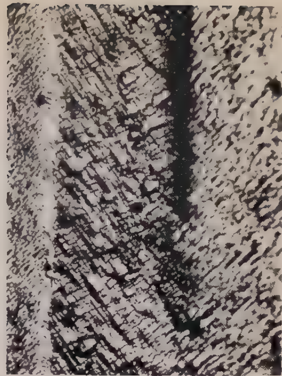

FIG. 18.—×500.

FIG. 19.—×200.

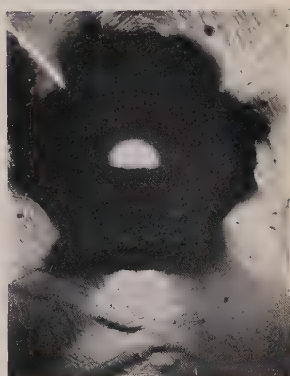

FIG. 20.—×100.

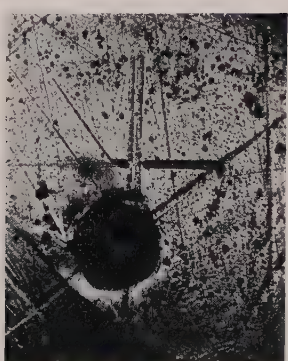

FIG. 21.—×60.

NOTE.—Figs. 17–21 are reproduced half-size.

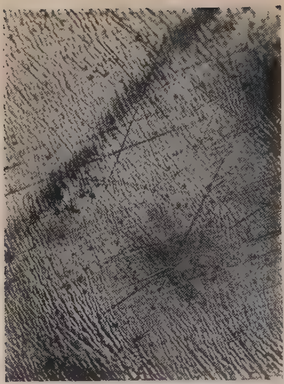

FIG. 22.—×350.

FIG. 23.—×50.

FIG. 24.—×100.

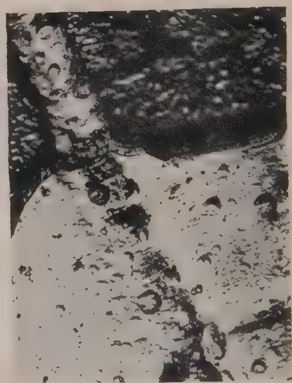

FIG. 25.—×350.

FIG. 26.—×350.

NOTE.—Figs. 22–26 are reproduced half-size.

[To face p. 4

of the larger one was logged, and the specimen was carefully repolished until free from pits and scratches, and etched to bring up grain boundaries. A Brinell impression (1-millimetre ball) made on the grain exposing a (001) face gave the expected "square" indentation, *but one or two straight "needles" ran out from the sides of the "square" at* 45°. The diagonal of the square was about 10° out of parallelism with the long axis of the strip. The specimen was next stressed along this same axis in a small tensile machine. At 5 tons per square inch deformation lines were visible to the naked eye, and the specimen was removed from the machine after a stress of 12 tons per square inch had been imposed. It was found to be covered with slip-bands.

A month elapsed before an opportunity arose for detailed examination, but it was then found that a straight "shadow effect" line ran through the indented crystal and continued straight through several others below it. This line ran at 45° to the sides of the "square" indentation, and it was made evident not by borders but by the shadow appearance produced when traversed by the slip-bands (Fig. 22, Plate LII.). This they did in a normal way for iron, the general inclination of the wavy slip-band system being at 70° (approx.) to the side of the "shadow line," which means an angle of 65° (approx.) with one side of the cube. Whether these wavy lines correspond to traces of a (112) plane making the theoretical angle of 63° to the side of the cube is not certain, though it is suggestive.

"*Surface Needles.*"—The cube face of this particular grain was found to be covered with "needles" similar to those reported on p. 426, Fig. 21 (Plate LI.). They lie in six major directions and are visible in Fig. 22. They had not been suspected when the specimen was polished and etched prior to straining, and so it is not known for certain whether they were in evidence at that time. After polishing alone they certainly were not noticed.

Another portion of the original strip was sawn off, polished with the usual care until free from all markings, and then etched in 2 per cent. alcoholic nitric acid. Needles were found in most grains, being more pronounced in some than in others. In any one grain several parallel series could be noticed, and generally they stopped short at grain boundaries. These needles have

been photographed on a grain whose etch pits were equilateral triangles with slightly curved sides. Such a grain cannot be exposing a (001) face, and consequently is not likely to be the least resistant to scratching influences. Ordinary surface scratches might therefore be expected to run across the boundary into the neighbouring grain. The specimen was carefully repolished and etched no less than four times, and on each occasion needle markings were found. In some instances etch pits could be seen to cross the boundaries of the needles without any apparent alteration of shape. Finally, a very long etching attack was given, and whilst some of the markings disappeared, others left channel effects in the surface.

The author is convinced that these needles are not ordinary surface scratches, though it seems quite likely that they may be due to some previous scratching effect. Though their directional habits often correspond with Neumann lamellæ, there is no proof that they are true twins. They appear to be superficial, and may simply be channels cut by the etching acid in ribs of metal cold-worked by scratching during the polishing process ; such metal would dissolve preferentially. Their reappearance after repeated polishing and etching would seem to exclude surface flow effects ; neither can it be shown that these " surface needles " are intersection bars.

After deciding against their being ordinary surface scratches, the author came across photomicrographs by Matweieff [17] showing similar markings, which Le Chatelier decided were Neumann lines formed by polishing. Portevin and Durand [18] disagreed with this conclusion for three reasons :

(1) There was evidence of their traversing boundaries,
(2) Deep etching removed some of them,
(3) They lay in eight directions instead of the maximum of six required by the (112) traces on a cube face ;

they declared that the markings were simply scratches. These objections do not appear to be conclusive. Concerning (1) certain lines are shown in Figs. 23, 24, and 25 (Plate LII.) in this paper which—whatever their nature—are not scratches, and yet cross some grain boundaries. Also a paper by Foley and Howell [19] shows Neumann bands, formed by shock, crossing boundaries.

As regards objection (2), if the needles are more or less superficial, deep etching should remove or obscure them, and concerning (3) much evidence has already been given that band markings (whether Neumann or otherwise) occur along both (112) and (100) planes. The paper by Foley and Howell further shows Neumann lines found by Professor C. Y. Clayton in unstrained Swedish iron, annealed at 1000° C., simply sectioned with a saw and then polished and etched. Professor G. Yamada was also reported therein to have found Neumann lines in pure unstrained iron heated at 1000° C. for thirty days and then sectioned, polished, and etched.

Special Bands in Coarse Ferrite.

Reverting to the author's last specimen, after the deep etching attack, fairly large twin-like markings were visible in two contiguous crystals which may themselves be twinned relative to each other. They can be seen in Fig. 23, but their origin is unknown. They present the following curious features when certain areas are examined at different magnifications :

(1) The broad parallel bands, light in colour, run right across one inner boundary, but stop short at the other two.

(2) These bright bands are crossed by others nearly at right angles (Fig. 26, Plate LII.). This second set also crosses the inner grain boundary with only a slight kinking effect.

(3) The bright bands all show almost square etch pits, and so does the bright grain into which some of them run. The orientation of the squares in the bands and grain is the same throughout, so far as can be seen by visual examination. The direction of the bands is parallel to the diagonal of the square.

(4) In the dark-etching grain the bright bands are clearly marked by sharp boundary lines, but this is not the case when they enter the bright cube-faced grain. In Fig. 23 the third band from the left is well defined in both grains, whereas the second from the right disappears. In Fig. 24 it will be seen that it does not actually cease but continues as a sort of " shadow line " (compare also Fig. 22).

This shadow line branches to its right after either crossing the spike-shaped marking or approaching the projection in the adjacent grain. This effect was most clearly seen when the microscope was run through the focus. Fig. 25 shows that even the third band from the right in Fig. 23 has no sharp borders in the cube-faced grain, but is visible by virtue of an etch furrow. Since the band appears to have the same surface orientation as the grain, divisiòn borders would not be expected.

The specimen was sealed in a quartz tube, which was evacuated before being heated to 930° C. for half an hour in an electric furnace. After cooling, and without any further polishing, it was subjected to an attack with 4 per cent. alcoholic nitric acid and examined at different times under the microscope. In this way the old and the new structures were made to overlap until eventually the surface markings of the former were dissolved away. Recrystallisation of the iron completely removed the bands, and the new structure bore no apparent relation to the old.

The Neumann Band Type of Marking.

Osmond and Cartaud had no doubts whatever that Neumann bands in ferrite were slabs of twinned material, and both Stead and Howe held the same view. At present the evidence for Neumann bands being twins is as follows:

(1) They have often parallel sides like twins,
(2) They deflect slip-bands as twins should do,
(3) They etch to a different tint from their background, which suggests that they have a different orientation,
(4) Parallel ones have identical orientation,
(5) The production of a twinned layer by simple deformation of ferrite along (112) planes appears to be easy (see p. 429).

Rosenhain and McMinn [16] have recently doubted whether the bands are really twins, and Bolsover suggests that they are simply preferential etching bands due to the increased potential energy possessed by planes which have undergone deformation. Against

this latter view the objection must be raised that they are sometimes visible by polish relief, and on the same argument slip-bands would always be expected to leave an etch trace. Nevertheless, there does not appear to be any perfectly conclusive evidence as to the orientation of the atoms within the lamellæ, for the etch pit observations do not appear to be very reliable. Portevin and Durand [18] show perfect square etch pits in a deeply etched Neumann band, which have the same orientation as perfect square etch pits well away from the Neumann band in the surrounding grain. This resembles the effects noticed by the author, and visible also in the strange bands discussed on p. 435, § 3. If the observation is correct it does not at once suggest twinning; but there is no certainty that deep etching has not removed or obscured the band itself, and that the etch channel does not simply betray the facets of the surrounding grain material.

After a study of the literature of the subject, the author has drawn up the following summary together with further observations of interest. It appears that Neumann lamellæ form:

(1) Readily in silicon ferrite at room temperatures even by static deformation.[6] (Ordinarily, silicon iron is of very large grain-size and is brittle under shock.)

(2) Readily in phosphoric ferrite (1·0 per cent. phosphorus) at 20° C., under conditions of deformation which will not produce them in pure ferrite.[20] (Phosphoric iron is generally of large grain-size and is brittle under shock.)

(3) Readily in pure ferrite even by slow deformation at the temperature of liquid air.[20, 21] (At this temperature the ferrite is brittle to shock.)

(4) Apparently readily at room temperatures in coarse ferrite produced by high-temperature annealing. Sawing, filing, and polishing, then, appear to be sufficient to produce them [19] (see p. 435). (Coarse ferrite is brittle under shock.)

(5) With difficulty in fine aggregates of ferrite. Static deformation, sawing, filing, and polishing do not ordinarily produce them, but very rapid deformation does, *e.g.* impact. (Fine ferrite is not ordinarily brittle under shock.)

The correlation between the ease of production of the Neumann type of line and the existence of large brittle grains, which is here evident, is striking. With regard to iron, it appears that the larger the crystal grain-size the greater the ease of production of Neumann lines and the smaller the resistance of the metal to shock. The locking effect of the irregular crystal boundaries appears to be great in determining the different properties of single crystals as compared with aggregates, and as the amount of grain boundary surface in unit volume of an aggregate of ferrite is reduced, the greater will be the freedom of the grains to deform like single crystals by (112) movement alone. The nearer the grains approach to being perfect crystals, with mathematically parallel planes (*e.g.* by long annealing and slow cooling) and the larger their size, the greater will be the effect in the mass for extensive well-defined planes of weakness to exist. Suitable stresses will find long atomic avenues which offer very little resistance to movement, and the degree to which the atoms themselves are vibrating should affect the freedom of gliding and the brittleness. At the temperature of liquid air the atoms in ferrite are confined within smaller amplitudes of vibration, and this may be the reason why the static Neumann lines are found at that temperature in material which is free from them at higher temperatures.

In α-brass Millington and Thompson [26] found multiple twinning which caused the metal to behave in a brittle way. Johnson [23] has shown what appear to be multiple twin needles in the brittle β-brass, and brittle martensite contains needles each of which is internally twinned. Zinc, cadmium, tin, antimony, and bismuth, do not crystallise in the cubic system like α-iron, but they are very prone to mechanical twinning in the cast state,[22, 25] and are relatively brittle to shock as compared with, say, normal copper, silver, or iron. As normally cast the former metals generally exist in much larger grains than the latter, and here again is a suggestion that reduced boundary locking facilitates typical crystalline deformation at the expense of the viscous type of flow.

Conclusions.

1. A single crystal of α-iron may be cleaved parallel to cube faces, and there is also evidence of (112) cleavage. Under static deformation it slips along the (112) plane. More than one direction of (112) planes may be involved.

2. Movement along the (112) plane in single crystals of α-iron is in agreement with the low elastic limit and the negligible change in density observed in previous experiments.

3. (i) If layers of atoms move along the (112) plane for a distance $\frac{\sqrt{3}}{2}$ of the side of the elementary cube a or a simple multiple of this, then no change of orientation will occur in the crystal of iron.

(ii) If movement takes place on successive (112) planes and proceeds for a distance $0 \cdot 577a$, then the moved portion of the crystal is twinned with respect to the original. In this way Neumann lamellæ may be formed.

4. If a surface slip-band be polished off, a trace of it is sometimes found on etching the metal beneath. This may be due to a certain amount of movement like type 3 (ii). When no trace is found, movement will be of the "complete" type 3 (i).

5. The evidence as a whole suggests that the crystals in an aggregate of ferrite slip along the (112) plane, and possibly the (001) is involved as well.

6. Conditions (such as large grain-size) which favour the easy production of Neumann lines within a metal appear to render that metal liable to brittleness.

The author wishes to acknowledge his indebtedness to Dr. A. J. Bradley for examining the structure of the silicon iron, and to Mr. R. W. James, M.A., B.Sc., for the X-ray tests on the cleavage prism of steel. He offers his best thanks for the very generous interest and encouragement extended by Professor F. C. Thompson throughout the course of the research, and for the facilities which have been provided for its prosecution.

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CORRESPONDENCE.

Mr. L. B. Pfeil (Swansea) wrote that he had recently been working along somewhat similar lines to those followed by Mr. O'Neill.[1] Where the two researches overlapped, the conclusions were for the most important part similar. That applied particularly to the conclusion that slip took place on the icosetetrahedral planes in α-iron, and to the explanation advanced to account for the formation of Neumann lamellæ. The author referred to a photograph of iron cleavage fragments, published by Professor Edwards and himself (Mr. Pfeil), and deduced evidence of cleavage on planes other than those of the cube. He (Mr. Pfeil) wished to point out that that was unjustifiable, for the fragments were not selected so that the surface of each coincided with a cube plane. For that reason the cleavages did not *appear* to be at right angles in every crystal, although in actual fact that was the case. He (Mr. Pfeil) had obtained no evidence of cleavage in iron crystals along planes other than those of the cube.

In the Carnegie Scholarship Memoir referred to above structures were shown and discussed, which were similar in some respects to that given by Mr. O'Neill in Fig. 15. There was no doubt that the lozenge-shaped areas had a different orientation from the surrounding material. That might be shown both by needle impressions and by the uniform deviation of slip-bands in passing from one to the other. Recently he (Mr. Pfeil) had obtained strong evidence that those areas were produced by a change in the orientation along planes parallel with the cube faces, and that the structure was fundamentally the same as the "slashes" referred to by Osmond and Cartaud. It did not appear to him that Mr. O'Neill's tentative explanation of the nature of that structure was likely to prove correct.

He agreed with Mr. O'Neill's statement that "surface needles" were not ordinary scratches. They were, however, closely connected with distortion produced in the early stages of the preparation of the surface, during the operations of sawing, filing, and coarse grinding. He was convinced that if sufficient care were taken in the preparation of the specimens no such effects as "surface needles" or "shadow effect" lines became evident on etching or on straining.

The author referred to instances where Neumann lamellæ had been reported in pure iron which had been sectioned, polished, and etched only. He (Mr. Pfeil) had in no instance ever produced a Neumann lamella either in a single crystal or in an aggregate by those operations; shock was always necessary. He was inclined to think that the cases in question might be due either to a confusion of the deep-seated

[1] L. B. Pfeil, "The Deformation of Iron, with Particular Reference to Single Crystals," *Carnegie Scholarship Memoirs*, 1926, vol. xv.

effects of scratches with true Neumann lamellæ, or to shock having been unknowingly applied. The latter appeared to be the more likely reason, for a low velocity blow from a small mass was all that was required to produce large numbers of the lamellæ in fully annealed carbon-free iron. He thought that no great difficulty should be encountered in differentiating between Neumann lamellæ and the grooves etched out beneath scratches. Many investigators appeared to etch very much too deeply to obtain the true structure of specimens showing Neumann lamellæ. With careful preparation and light etching they could always be obtained as narrow white lines separated

Fig. A.

Fig. B.

from the white ground by clearly defined black boundaries. Furrows produced by the etching reagent in places where the crystal had been altered during preparation never, in his experience, had an appearance of that character.

The author set out as an objection to the conclusions of Portevin and Durand that Neumann lamellæ sometimes crossed crystal boundaries. He (Mr. Pfeil) had often seen cases where that appeared to occur. It seemed likely, however, that if a given stress produced a Neumann lamella readily in a certain direction in one crystal, it would tend also to produce one in the same direction in an adjacent crystal. As a rule, the second crystal would not be so oriented as to make that possible, but there were a number of orientations for the second crystal which would allow a lamella to be produced in the same direction. When the second crystal was not so set, the lamellæ, if

produced, would be in a different direction. In some cases, however, the tendency for the one direction to be continued was so great that a large number of very short lamellæ were produced in "échelon" so as to continue the direction followed in the first crystal. An interesting example of that was shown in Fig. A, in which there were several examples of the "échelon" formation (Armco iron, etched in 5 per cent. picric acid, magnified 100 diameters).

When the second crystal was set very near to one of the special orientations, the lamellæ would *appear* to continue in a straight line across the boundary. An example of that was shown in Fig. B (Armco iron, etched in 5 per cent. picric acid, magnified 100 diameters). The central crystal had nine lamellæ, eight of which had a common direction. Of those nine lamellæ, three appeared to cross the boundary into the crystal below without change in direction, while one crossed with a small deflection. Closer investigation showed that on crossing the boundary there was a change in the thickness of the lamellæ, and a straight-edge would show a very small deflection in those three which appeared at first sight to be straight. In his opinion, Neumann lamellæ never crossed boundaries, but they sometimes appeared to do so owing to a lamella in each of two crystals having nearly or exactly the same direction and meeting at the same point on the boundary.

He thought that the author's "surface needles," and probably also his "special bands," were fundamentally the same as the "second order" lines of Matweieff, which were discussed by Portevin and Durand. He thought that they were all due to the distortion of the crystals below the scratch furrows, and that they had no real similarity with Neumann lamellæ.

The Author, in reply, wrote that he was glad to receive Mr. Pfeil's communication, and to learn that his experiments confirmed the slipping of α-iron on the (112) plane. He would look forward with great interest to reading the Carnegie Memoir containing the results of Mr. Pfeil's work.

Concerning the reference to the cleavage fragments shown by Professor Edwards and Mr. Pfeil, unless the surfaces corresponded approximately to a (001) plane then it was of course true that angular measurements on a random face were practically of no value. A cube face was the condition which he (Mr. O'Neill) had made before attaching any significance to the cleavage trace angles of the fragments. The impression gained by reading p. 143 of the paper by Professor Edwards and Mr. Pfeil was that a case was there being made for a regular orientation of the crystals produced by their method, and at first he thought that the fragments illustrated had been selected *at random* from the many pieces remaining from a single broken grain orientated as suggested.

He believed that Mr. Pfeil was in agreement with him as to the cause of both "surface needles" and the "special bands." It seemed

likely that the scratching influences would act most potently along the (112) traces, and the "surface needles" produced would then lie in the same direction as the Neumann lines. Portevin and Durand had rejected the suggestion of Matweieff and Le Chatelier that "second order" lines were Neumann lamellæ for the reasons given in the paper, but the question of boundary-crossing did not appear to have received much consideration by the former workers. In that respect the Neumann line theory was dismissed by them with the simple statement

Fig. C.

that some of Matweieff's lines "se prolongent d'un grain sur un autre sans s'infléchir." In view of the additional evidence now put forward by Mr. Pfeil that Neumann lamellæ sometimes *appeared* to cross grain boundaries with very little or no change of direction, he (Mr. O'Neill) still felt that Portevin and Durand had not conclusively proved their point. The traces on a given plane of (112) planes in adjacent crystals might under certain conditions be exactly collinear, and Mr. Pfeil had pointed that out; but further still, if two adjacent grains were relatively twinned about the plane of a Neumann lamella, then the latter would be common to both. In the paper it was suggested that Fig. 23 could be explained on those grounds.

It had been pointed out to the author that if a wedge had been produced by slip along *ABC* (Fig. 3), then the relative direction of

atomic movement would be the reverse of that described on p. 429. Instead of spheres 1 and 2, for instance, moving over to the left to touch the sides of 4 and 5, as shown in Fig. 6 (*d*), they would travel from left to right and come against the right-hand side of spheres 5 and 6. The general effect would still be the same, but different distances would be travelled in the two cases. Thus in Conclusion 3 (ii) the distance $0 \cdot 577a$ referred to slip proceeding from left to right in Fig. 6. In the opposite direction a traverse of $0 \cdot 289a$ would be necessary to give twinning, and that was the figure required to fit the description given on p. 430.

It might be objected that the two-dimensional examination of the markings represented in Fig. 2 was only consistent with (112) slipping in the (111) direction which the author had advanced. A further study of region D (Fig. 2) had therefore been made with the object of finding the direction of the surface steps in a plane at right angles to that of the paper. Fig. C showed the edge XZ of the plane of section XYZ (Fig. 1 (*a*)) running vertically at the right of the photograph, and slip steps on the surface of the wedge might be seen running at right angles to that edge. (Their somewhat blurred appearance was due to the repeated etching attacks to which the specimen had been subjected.)

Those surface steps were then carefully filed down, and the flat produced was polished and deeply etched. Grooves corresponding in direction to the surface markings were etched out of the specimen by that treatment, but instead of giving the appearance of inlaid slabs they resembled slightly twisted strips. The direction of those traces at right angles to the plane of section XYZ fixed the slip plane in three dimensions as being parallel to the (112).

Iron and Steel Institute.

ON THE RELATION BETWEEN THE LATTICE-CONSTANT AND THE DENSITY OF IRON-NICKEL ALLOYS.[1]

By ATOMI ÔSAWA (Japan).

Introduction.

In 1921 Andrews[2] investigated nickel steel containing about 25 per cent. nickel, and showed its lattice to be face-centred cubic; after cooling in liquid air, the lattice mostly changed into the body-centred cubic form. The X-ray analysis of the complete series of nickel and iron alloys was recently made by McKeehan.[3] According to his result, the alloys containing 0 to 25 per cent. of nickel had the body-centred cubic lattice like pure iron, and with nearly the same spacings; in the region between 25 and 30 per cent. of nickel, both the body-centred and face-centred cubic lattices coexisted, while all the alloys with over 30 per cent. of nickel had the face-centred cubic lattice. He found also that at the temperature of liquid air the body-centred lattice persisted up to a little higher than 30 per cent. of nickel.

The present investigation was undertaken to study the relation between the lattice-constant and the density in the case of iron-nickel alloys; it was intended to determine whether the variation of the density with respect to the concentration of nickel were explained by that of the lattice-constant, especially in the case of the irreversible nickel-irons.

Experimental Details.

Twelve Debye-Scherrer's X-ray photographic cameras were used simultaneously. A Coolidge tube with a molybdenum anti-cathode was actuated by a high-tension transformer giving 30 kilovolts and 5 milliamperes; the exposure required was

[1] Received July 22, 1925.
[2] *Physical Review*, 1921, vol. xviii. p. 657.
[3] *Ibid.*, 1923, vol. xxi. p. 402.

twenty-five hours. The camera constants were determined by means of the spectral lines of Armco iron.

All specimens of the iron-nickel alloys were prepared by alloying Armco iron with pure nickel in a Tammann furnace, and cooled slowly; they were remelted in order to drive off the absorbed gases, and again slowly cooled to room temperature. They were then severely forged to eliminate possible blowholes, and were annealed at 1150° C. for one hour, followed by a slow cooling. They were filed into 10 millimetres square rod, cut near both ends, and examined microscopically for blowholes and slag inclusions. Those specimens which showed no trace of such faults were subjected to the density determination and X-ray analysis. The samples used for the latter were of cylindrical form, 0·5 millimetre diameter and 10 millimetres long, made of powder filed out with new files, after the density measurement was made.

Chemical Analysis.—Since the samples contained, besides iron and nickel, only a very small quantity of impurities, a complete

Ni per Cent.	Mn per Cent.	S per Cent.	P per Cent.	Cu per Cent.	Si per Cent.	Co per Cent.	C per Cent.	Fe per Cent.
5·21	nil	0·023	trace	0·043	0·008	trace	nil	94·72

analysis was made for the first sample only as an example. The result was as given in the above table.

TABLE I.

No.	Nickel (cal.).	Nickel per Cent.	Carbon per Cent.	Iron per Cent.	No.	Nickel (cal.).	Nickel per Cent.	Carbon per Cent.	Iron per Cent.
1	5	5·21	trace	94·72	15	35	35·25	...	64·68
2	10	6·70	0·057	93·23	16	40	41·21	trace	58·72
3	15	14·41	trace	85·51	17	45	41·33	...	58·60
4	20	22·13	0·023	77·80	18	50	52·96	0·019	46·97
5	25	27·07	trace	72·86	19	55	57·46	...	42·47
6	26	25·79	...	74·14	20	60	63·94	...	35·99
7	27	29·00	0·021	70·93	21	65	65·75	...	34·18
8	28	27·66	...	72·27	22	70	73·48	trace	26·45
9	29	29·98	0·009	70·00	23	75	78·12	...	21·81
10	30	30·39	...	69·54	24	80	82·25	...	17·68
11	31	34·42	0·067	65·51	25	85	85·58	...	14·35
12	32	31·55	...	68·38	26	90	91·00	trace	8·93
13	33	32·64	0·051	67·29	27	95	96·16	...	5·74
14	34	35·27	...	64·66					

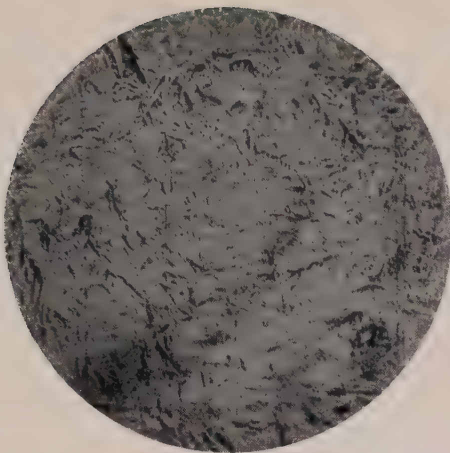

FIG. 5.—27 per cent. Nickel. Cooled in liquid air. ×100.

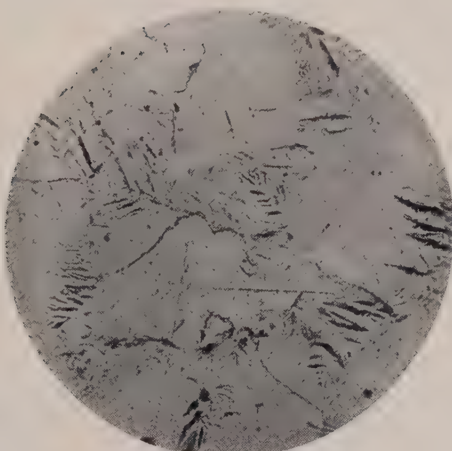

FIG. 6.—29 per cent. Nickel. Cooled in liquid air. ×100.

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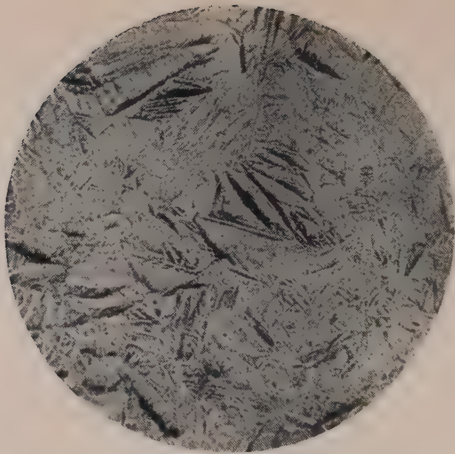

FIG. 7.—30 per cent. Nickel. Cooled in liquid air. ×100.

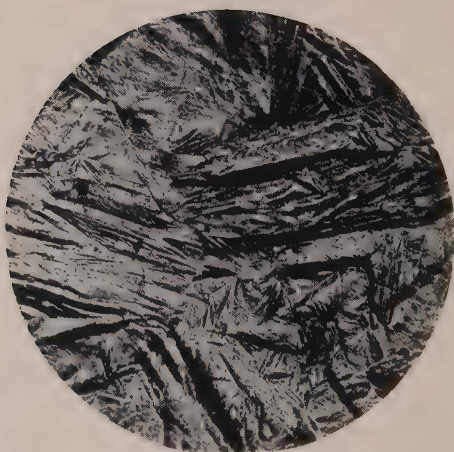

FIG. 8.—31 per cent. Nickel. Cooled in liquid air. ×100.

For the remaining samples, iron, nickel, and carbon analyses only were made. The figures are given in Table I.

Results of Experiments.

Lattice-Constants.—Lattice-constants given in Table II. are the mean of three values obtained from different films.

Table II.

Alloy. Nickel per Cent.	Annealed at 1150° C.		After Immersion in Liquid Air.	
	Body-Centred Cubic.	Face-Centred Cubic.	Body-Centred Cubic.	Face-Centred Cubic.
	$a \cdot 10^8$ cm.	$a \cdot 10^8$ cm.	$a \cdot 10^8$ cm.	$a \cdot 10^8$ cm.
0	2·865	...	2·865	...
5	2·866	...	2·865	...
10	2·870	...	2·870	...
15	2·871	...	2·872	...
20	2·873	...	2·874	...
25	2·876	(weak)	2·874	...
26	2·873	,,	2·875	...
27	2·877	3·600	2·879	...
28	2·875	3·590	2·878	(weak)
29	2·879	3·600	2·878	,,
30	2·877	3·605	2·876	,,
31	2·877	3·596	2·875	,,
32	2·875	3·596	2·872	3·598
33	(weak)	3·597	2·874	3·599
34	...	3·597	(weak)	3·598
35	...	3·596	...	3·595
40	...	3·595	...	3·596
45	...	3·592	...	3·593
50	...	3·589	...	3·587
55	...	3·584	...	3·584
60	...	3·582	...	3·584
65	...	3·576	...	3·578
70	...	3·568	...	3·568
75	...	3·561	...	3·560
80	...	3·551	...	3·550
85	...	3·549	...	3·548
90	...	3·543	...	3·544
95	...	3·540	...	3·540
100	...	3·538	...	3·538

In the alloys containing from 25 to 33 per cent. of nickel, two spectra, arising from the face-centred and body-centred lattices, were mixed, and the (111) line of the former lattice and the (110)

line of the latter coincided, so that that line was much blackened in comparison with other lines. Hence in those cases, the spectrum distance between $(110)^2$ and (211) lines was measured. Fig. 1 shows the relation between the lattice-constants and the concentration of nickel.

The fact that in iron-nickel alloys there is a heterogeneous range between 25 and 30 per cent. of nickel is evident from the equilibrium diagram of the system proposed by Honda. The

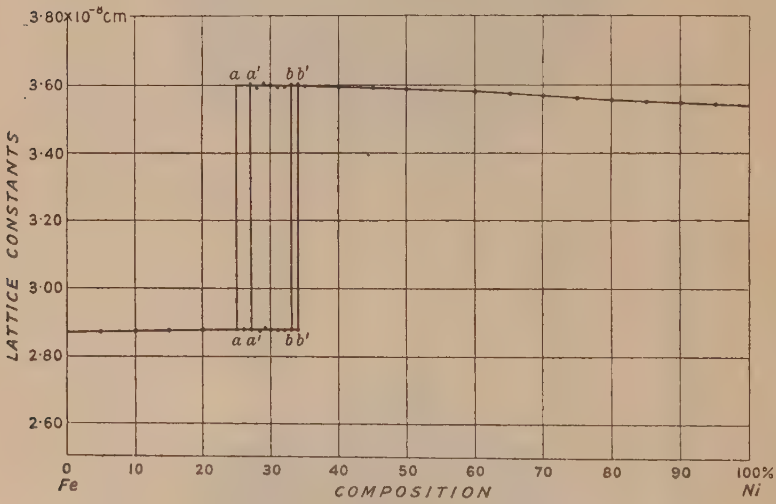

FIG. 1.

A3 point of iron falls rapidly as the percentage of nickel increases; above the A3 line the alloys are in the γ-phase, but below it, in the α-phase, and between these two homogeneous systems there must be a heterogeneous system consisting of α- and γ-phases. It should also be observed that the dotted curve *ab* in Fig. 2, which is usually given in the equilibrium diagram of iron and nickel and represents the magnetic transformation of these alloys, does not represent a change of phase, but only an interatomic change like the A2 transformation in iron, and should therefore be excluded from the diagram based on the phase rule.

From Fig. 2 it is easily perceived that the concentration of nickel alloys corresponding to the heterogeneous region is raised,

and also the range of the latter is widened, by immersing these alloys in liquid air.

In Fig. 1 the alloys lying between lines *a* and *b* consist of two constituents, α and γ; the same remark applies to those alloys between lines *a′* and *b′*, which were immersed in liquid air beforehand. The two lattice constant-concentration curves for α and γ configurations are almost straight. In the region where the α and γ types of spectrum are mixed, the α and γ lattice-constants

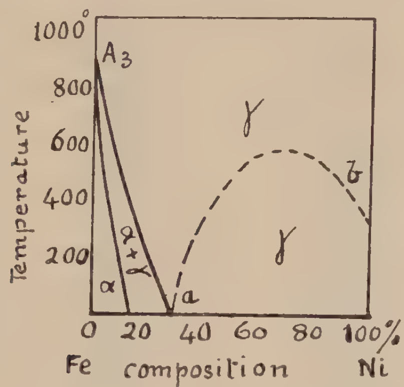

FIG. 2.—Equilibrium Diagram Fe–Ni. (Honda.)

are, respectively, nearly the same as those immediately below and above this region.

Density.—For the measurement of the density, the surfaces of the samples were polished with emery-paper and moistened with a wet cloth to remove any bubbles which might adhere to the surface when they were suspended in water. A copper wire, 0·1 millimetre in diameter, which supported the samples in the water, was also moistened before weighing. Table III. shows the results of the determinations, and in Fig. 3 the density is plotted against the concentration of nickel.

In Fig. 3 dots show the densities of annealed samples, and crosses those of the same samples immersed beforehand in liquid air. As the nickel content increases, the density curve bends slightly upwards to 26 per cent. nickel, then it increases rapidly to 33 or 35 per cent. nickel, and afterwards increases more slowly to pure nickel. For the irreversible iron-nickels (15 to 35 per cent.

nickel) previously immersed in liquid air, the density curve lies somewhat below that of the annealed samples; in other alloys the density is not affected by immersing them in liquid air. The

TABLE III.

Alloy. Nickel per Cent.	Annealed at 1150° C. for One Hour. Density.	After Immersion in Liquid Air. Density.	Calculated Density.
0	7·8787	7·8795	7·8820
5	7·8777	7·8795	7·887
10	7·8926	7·8933	7·888
15	7·9062	7·9001	7·893
20	7·9243	7·9205	7·896
25	7·9498	7·9274	7·897
26	7·9487	7·9281	...
27	7·9808	7·9447	...
28	8·0058	7·9582	...
29	8·0188	7·9782	...
30	8·0347	7·9773	7·898
31	8·0659	8·0653	...
32	8·0973	8·0147	...
33	8·1228	8·0662	...
34	8·1292	8·1267	...
35	8·1293	8·1275	8·108
40	8·1445	8·1487	8·118
45	8·1302	8·1323	8·173
50	8·2379	8·2338	8·212
55	8·2520	8·2553	8·263
60	8·3365	8·3378	8·326
65	8·2799	8·2785	8·287
70	8·4489	8·4432	8·455
75	8·5103	8·5131	8·510
80	8·6049	8·5946	8·559
85	8·6536	8·6587	8·655
90	8·7311	8·7395	8·730
95	8·8211	8·8250	8·805
100	8·8989	8·8981	8·898

density calculated from the lattice-constants, assuming that iron and nickel atoms make a simple substitution, is also plotted in Fig. 3 by dotted circles; in alloys containing more than 35 per cent. nickel, the observed and calculated densities coincide.

The density of a binary alloy forming a solid solution of a given lattice by simple substitution may be obtained from those of its components from the following equation:

$$\rho = \frac{n \times 1{\cdot}66 \times 10^{-24}}{\left(\frac{a}{\alpha} + \frac{b}{\beta}\right) d^3} \times 100$$

where ρ is the density of the alloy, n the number of atoms contained in an elementary cube, being 2 for a body-centred and 4 for a face-centred cubic lattice, a and b are weight per cents. of the two components, α and β their atomic weights, and d the lattice-constant.

In the case of γ-iron-nickel, d has a nearly constant value, and therefore the above relation represents a hyperbola, ρ being considered as a function of the concentration. From the observed

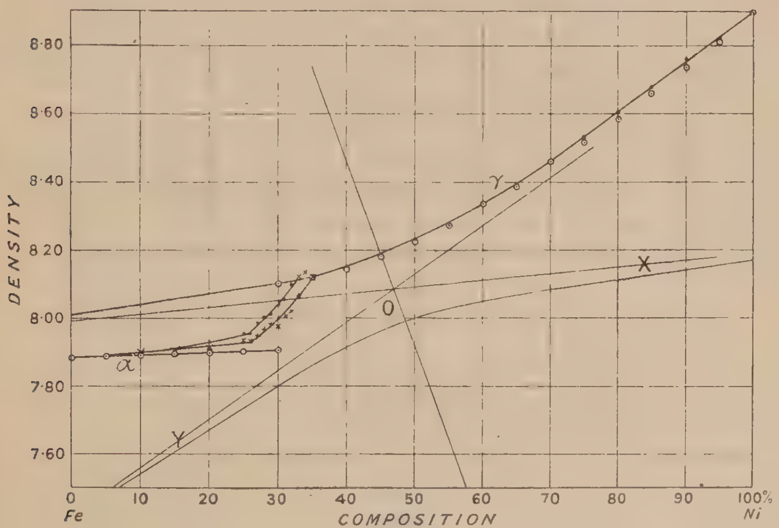

FIG. 3.

curve the traverse axes and the asymptotes OX and OY have been determined graphically. In this way, if this hyperbola branch be produced to the lower percentage of nickel, it intercepts the density axis of pure iron at $8 \cdot 008$, which is the density of γ-iron at ordinary temperature. If this value be substituted in the above relation, then $d = 3 \cdot 593$ Å. Westgren obtained as the lattice constant of γ-iron, at 1000° C., a value $d = 3 \cdot 60$ Å. By using the expansion coefficient of pure iron given by Sato, the above value of d was calculated to that at 15° C. and found to be $d = 3 \cdot 591$ Å. The agreement of these two figures is very satisfactory.

The densities of the alloys with less than 25 per cent. of nickel

were also calculated by assuming the space-lattice to be body-centred cubic, and are shown by dotted circles in Fig. 3. The fact that the densities of the alloys lying between 10 and 25 per cent. of nickel did not coincide with the calculated values, even in the case of samples immersed in liquid air, shows that during cooling the majority of the atoms changed from the γ to the α configuration, but that some γ-iron or austenite remained untransformed, and so gave those alloys a greater density than that calculated on the assumption of α configuration. Hence from the determination of the densities so far referred to, it is concluded that the heterogeneous range of iron-nickel alloys at room temperature lies between 15 and 35 per cent. of nickel.

In the alloys containing 15 to 35 per cent. of nickel, austenite and martensite are mixed together in a considerable proportion; their density being known from Fig. 3, the relative proportion of austenite and martensite can be calculated from the observed densities. Table IV. shows the results of these calculations.

TABLE IV.

Alloy. Nickel per Cent.	Austenite in Annealed Samples. Per Cent.	Austenite in Samples Dipped in Liquid Air. Per Cent.
15	4·6	4·6
20	14·0	8·9
25	18·8	13·5
26	18·7	13·7
27	30·1	20·4
28	39·6	27·8
29	41·5	34·9
30	50·8	34·7
31	62·2	48·3
32	73·5	51·7
33	100·0	74·0
34	100·0	100·0

As seen from Fig. 3, in the case of alloys containing less than 35 per cent. nickel, the densities are less for the samples immersed in liquid air than for the annealed samples; this confirms the theory that some austenite is transformed into martensite during cooling in liquid air. Figs. 5–8 (Plates LIII. and LIV.) show the microscopic structures of four of these alloys dipped in liquid air.

Hardness.—The Brinell hardness of the specimens was measured by using a steel ball $\frac{1}{16}$ inch in diameter and a load of 75·67 kilogrammes per square millimetre. The results are shown graphically in Fig. 4.

In annealed samples, the hardness-concentration curve rises steadily with increasing nickel content to 20 per cent., and after passing through a maximum decreases rapidly to 31 per cent. of nickel; from this point the decrease of the hardness with the

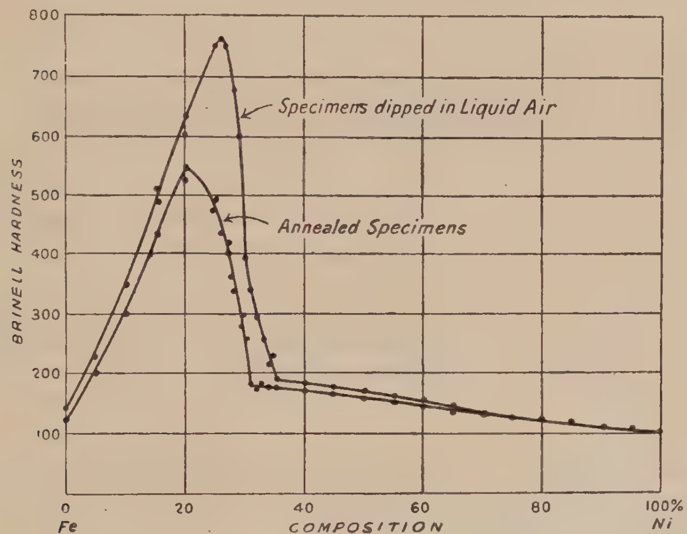

Fig. 4.

increasing content of nickel is very slow. With samples dipped in liquid air, the course of the hardness curve is similar to the above, but the maximum hardness is much greater than that for annealed samples, and the concentration for the maximum is about 5 per cent. higher.

The increase of hardness in these two states with the content of nickel is due to the presence of the increasing amount of martensite, and its decrease to the gradually increasing austenite. In the case of nickel alloys, the velocity of the A3 transformation is very small, so that a slow cooling, such as cooling in a furnace, causes a hardening of the alloys, due to a martensitic structure.

Even the austenite is also arrested and is found mixed in the martensite. By immersing these samples in liquid air, the arrested austenite changes into martensite, thus causing a considerable increase of hardness, as noted above.

Summary.

1. For the whole series of iron-nickel alloys, the lattice constants and the densities were determined, both for the annealed samples and those dipped in liquid air. The hardness of these samples was also measured.

2. For the iron-nickel alloys, the view that the solid solution consists of a simple substitution of iron and nickel atoms agrees with the result of the density determination.

3. The heterogeneous range of iron-nickel alloys lies between 12 and 33 per cent. of nickel at room temperature, and between 15 and 35 per cent. at the temperature of liquid air.

4. The hardness-concentration curves for iron-nickel alloys show the presence of martensite and austenite even in slowly cooled samples. The maximum hardness is attained at 21 and 27 per cent. of nickel for the annealed and severely cooled samples, respectively.

In conclusion, the author wishes to express his hearty thanks to Professor K. Honda, under whose kindly guidance these experiments have been carried out.

Iron and Steel Institute.

THE ESTIMATION OF PHOSPHORUS IN STEELS CONTAINING TUNGSTEN.*

By T. E. ROONEY, A.I.C., A.M.S.T., and L. M. CLARK, B.A., Ph.D., A.I.C.
(The National Physical Laboratory.)

Methods have been published for the estimation of phosphorus in ferro-tungsten and tungsten-bearing materials by C. M. Johnson [1] in 1913, and by Gray and Smith [2] in 1919. In both papers attention is drawn to the fact that in separating tungstic acid by evaporation with hydrochloric acid, an appreciable amount of the phosphoric acid present is retained with the tungstic acid.

The method described by Johnson deals with the determination of phosphorus in ferro-tungsten, metallic tungsten powder, and tungstic acid by direct solution. In the case of ferro-tungsten he recommends decomposing the material by treatment with concentrated nitric acid, with the addition of a small amount of hydrofluoric acid, boiling until a clear solution is obtained. The solution is evaporated to dryness but not baked; hydrochloric acid is added, and the solution is again evaporated to dryness. The residue is heated with hydrochloric acid, water is added, and the bulk of the tungstic acid is filtered off, the remainder being removed by concentrating, diluting, and refiltering. The phosphorus is estimated in the filtrate.

The phosphorus is removed from tungsten or tungsten oxide by prolonged digestion of the finely powdered sample with concentrated hydrochloric acid, with the addition from time to time of small quantities of potassium chlorate. Metallic tungsten powder is first roasted until converted into the yellow oxide, and is then treated in the same way.

The experience of the present authors has shown that although treatment with nitric acid and hydrofluoric acid may decompose phospho-tungstic acid, the subsequent operations of

* Received January 22, 1926.

evaporation with hydrochloric acid will result in the retention of some of the phosphoric acid by the separated tungstic acid. They carried out a large number of experiments on steels of various tungsten content, using Johnson's method of digestion with hydrochloric acid and potassium chlorate; in the case of steels of low tungsten content the method was fairly successful, but with steels of higher tungsten content and with tungsten steels to which known amounts of phospho-tungstic acid had been added, complete separation of the phosphoric acid was not obtained.

The method described by Gray and Smith appeared to be unnecessarily long and complicated when dealing with steels containing not more than 20 per cent. tungsten. They recommend that alloy steels should be dissolved in nitric acid, the solution evaporated to dryness, and the ferric nitrate baked to convert it to oxide. The resulting oxide, &c., is fused with nitre mixture, the melt dissolved in water, filtered and washed. The residue is ignited, dissolved in hydrochloric acid, and evaporated. The filtrate is acidified with hydrochloric acid, and bromine is added in excess. Ammonia is added to dissolve the tungstic acid and an excess of strong ammonia added. The mixture is cooled and the phosphorus present is precipitated with magnesia mixture.

The magnesium ammonium phosphate is dissolved in hydrochloric acid, added to the iron solution, and evaporated to dryness. The residue is dissolved in hydrochloric acid. Arsenic, tin, &c., are removed with sulphuretted hydrogen. A small amount of ferric chloride is added, and the iron is precipitated as ferric acetate. The ferric acetate which contains all the phosphorus is dissolved in hydrochloric acid, oxidised with nitric acid and reprecipitated with ammonia. The precipitate is dissolved in nitric acid, and the phosphorus precipitated with ammonium molybdate as usual.

The authors carried out estimations on a number of tungsten steels of low phosphorus content in the manner described by Gray and Smith. In some cases no phosphorus was detected, and in others the results were too low. It was found that the precipitation of small quantities of magnesium ammonium phosphate in presence of tungsten is very uncertain.

Description of Experimental Work.—Preliminary work by the

authors included endeavours to decompose phospho-tungstic acid by digestion with various mixtures of acids and by the use of potassium chlorate, as described by Johnson. The freedom of the tungstic acid precipitate from phosphoric acid was tested by solution in ammonia and the addition of magnesia mixture, but, as noted above, this method was not reliable in detecting small quantities of phosphorus.

The scope of direct solution methods was found to be very limited, as, in the case of tool steel and steel of a similar tungsten content, a small amount of phosphoric acid was always retained in the tungstic acid residue. For example, a tool steel with a total phosphorus content of 0·027 per cent. yielded 0·021 per cent. by a direct solution method.

It was finally decided to examine the possibility of separating quantitatively the phosphoric acid retained by the tungstic acid by dissolving in ammonia, adding a small amount of ferric chloride, making acid with hydrochloric acid, and reprecipitating the iron as ferric hydroxide in order to determine if the phosphoric acid were completely retained by the precipitate.

For this purpose two steels of the composition given in Table I. were employed; W was a tungsten steel and G a typical commercial tool steel.

Table I.

	Steel W.	Steel G.
	Per Cent.	Per Cent.
Carbon . .	0·39	0·63
Silicon . .	0·21	0·22
Tungsten . .	15·35	16·16
Chromium . .	0·14	4·16
Vanadium . .	...	1·25
Molybdenum .	...	...

The amount of phosphorus in the different samples analysed was varied by the addition of weighed portions of a sample of phospho-tungstic acid in which the phosphorus had been carefully determined. A large number of determinations were carried out in order to find the best conditions, and as a result the following method was adopted:

PHOSPHORUS IN TUNGSTEN STEEL.

Two grammes of steel drillings are digested with 40 cubic centimetres of concentrated hydrochloric acid and 20 cubic centimetres of concentrated nitric acid on a steam bath until decomposed. The mixture is then evaporated to dryness and baked until all fumes are driven off. After cooling, the residue is heated with 50 cubic centimetres of hydrochloric acid and evaporated to low bulk. A further 50 cubic centimetres of hydrochloric acid is added and the mixture boiled for a few minutes to ensure that all the iron is in solution. 60 cubic centimetres of water is then added, the mixture again boiled for a short time, allowed to stand on a steam bath for fifteen minutes and then allowed to cool. The tungstic acid residue is filtered off on a pulp filter and washed twice with cold water. The filtrate is evaporated on a hot-plate, and the tungstic acid residue is dissolved in warm ammonia (1 : 1) and the filter washed with hot water. A small portion of the iron solution is added to the ammoniacal solution, which is then rendered slightly acid with hydrochloric acid. A small excess of ammonia is added, and the mixture heated on a steam bath for a short time until the ferric hydroxide settles out. The precipitate is filtered off and washed twice with warm water. Usually one precipitation with ferric hydroxide is sufficient to separate the phosphoric acid from the tungstic acid, but with high percentages of phosphorus two precipitations may be necessary. As a rule, a small amount of tungstic acid is carried down with the ferric hydroxide, and it is necessary to dissolve this precipitate in hydrochloric acid and reprecipitate with ammonia. The reprecipitated ferric hydroxide is dissolved in hydrochloric acid and added to the main iron filtrate, and the whole evaporated to low bulk. Two evaporations are then made with nitric acid (50 cubic centimetres each time) to remove hydrochloric acid, the final evaporation being continued until about 15 cubic centimetres remain. Water is added, and any tungstic acid which separates is filtered off and treated for the recovery of any phosphoric acid with which it is combined, as described for the main bulk of the tungstic acid residue. The ferric hydroxide in this case is dissolved in hot dilute nitric acid (specific gravity, 1·1) and added to the main nitric acid solution. The phosphorus

in the solution is estimated by precipitation with molybdate solution, and the phospho-molybdate formed titrated with alkali in the usual way. In the presence of vanadium the precipitation of the phospho-molybdate is carried out by the method recommended by Cain.[3]

In Table II. are shown the results obtained with a series of samples prepared by adding weighed portions of phospho-tungstic acid to the steels W and G.

TABLE II.

Sample.	Weight of Phospho-tungstic Acid Added.	Phosphorus.	
		Total Present.	Found.
	Grm.	Per Cent.	Per Cent.
G	None	0·027	0·027
G	0·05	0·052	0·051
G	0·10	0·076	0·074
G	0·15	0·101	0·100
W	None	0·019	0·019
W	0·05	0·043	0·043
W	0·10	0·068	0·065
W	0·15	0·092	0·090

The addition of 0·05 gramme of phospho-tungstic acid is equivalent to 0·0245 per cent. of phosphorus.

As a further test of the method, samples were prepared by melting 100-gramme lots of the steels W and G and adding weighed quantities of a sample of iron containing about 6 per cent. of phosphorus. The phosphorus in these samples was estimated by the method described, and results are given in Table III.

TABLE III.

Sample.	Phosphorus.
	Per Cent.
W2	0·54
W3	0·084
G2	0·072

Less difficulty was experienced with the analysis of these latter samples than with the mixtures of steel and phosphotungstic acid, and the results obtained approximate fairly well to the percentage of phosphorus aimed at in preparing the ingots.

Since completing the work the attention of the authors has been directed to a paper published by Lundell and Hoffman,[4] giving a method which is very similar to the one described in this paper. The main point of difference is that they recommend the use of alum in place of ferric chloride for separating the phosphoric acid from the tungstic acid residue. They do not give any table of results obtained by their method. Apparently no precautions are taken to recover the phosphoric acid from any small portions of tungstic acid which may separate during the later stages of the process.

Lundell and Hoffman regard the method as a standard method only, and for routine determinations state that the small phosphorus content of the tungstic acid may be disregarded. The experience of the authors of the present paper and the results published by Gray and Smith show that a considerable proportion of the phosphorus can be retained by such tungstic acid residues.

In conclusion, the authors wish to thank Dr. Rosenhain, F.R.S., for permission to carry out the work in the Metallurgy Department of the National Physical Laboratory, and Dr. W. H. Hatfield of the Brown-Firth Research Laboratories for kindly presenting the steels used in this research.

REFERENCES.

(1) *Journal of Industrial and Engineering Chemistry*, 1913, vol. v. p. 297.
(2) *Journal of the Iron and Steel Institute*, 1919, No. I. p. 585.
(3) *Technical Papers of the Bureau of Standards*, 1913, No. 24.
(4) *Journal of Industrial and Engineering Chemistry*, 1923, vol. xv. pp. 44, 171.

CORRESPONDENCE.

Mr. A. T. Etheridge, M.B.E., B.Sc. (Woolwich), wrote that he quite agreed with the authors that the estimation of very small amounts of phosphorus, as in steels, was not satisfactory by the magnesium-ammonium-phosphate precipitation method. Apart from any solvent action of ammonium tungstate, the precipitate was so small that the solubility coefficient under the best conditions was not negligible, as it would be in dealing with larger amounts of phosphorus. He also agreed that the purification of tungstic acid by hydrochloric acid was difficult. In his experience with tungsten-vanadium steels it had been found necessary to repeat the treatment with hydrochloric acid in order to bring down the occluded vanadium to a negligible quantity.

The method described by the authors was practically identical with that which had been used in the Research Department, Woolwich, for several years. It might be of interest to add that it had been found that most of the occluded phosphorus was recoverable by solution in ammonia and filtration. The precipitate contained iron and practically all the phosphorus, possibly as ferric phospho-tungstate. At any rate, with low phosphorus steels (0·03 per cent.) practically no more phosphorus was recovered from the ammonium-tungstate filtrate. That might possibly be caused by the fact that the solution of the steel was evaporated down to a paste and not baked, as described by the authors. He did not recommend baking, as that had been found to increase the occluded impurities to a marked extent.

Mr. N. D. Ridsdale (Middlesbrough), wrote that he had done a good deal of work in 1920 in connection with the analytical standardisation of a chrome-vanadium-tungsten-cobalt alloy steel for phosphorus. Mr. Rooney had kindly furnished him with samples of three of the tungsten steels mentioned in the paper, and he (Mr. Ridsdale) had analysed them by the quick method he had evolved, with the following results :

	Phosphorus.	
	Messrs. Rooney and Clark's Method. Per Cent.	Mr. Ridsdale's Method. Per Cent.
Steel W	0·019	0·026
,, G	0·027	0·025
,, G2	0·072	0·073

The results were in good agreement, with the exception of steel W, where a little tungstic oxide had interfered through not being filtered off before precipitation. The test would have been repeated by the modification (see note 2 below) on 2·8 grammes, but there was no more of the sample left.

The method was a development of the one published in the *Journal of the Iron and Steel Institute*, 1911, No. I. p. 346. Its success mainly depended on the fact that by digesting in as little nitric acid as possible the black residue containing chromium, tungsten, &c., could be brought into solution by means of a large excess of potassium permanganate. Hydrochloric acid and some other compounds used for clearing the excess manganese oxides tended to bring down tungstic oxide, whereas ammonium oxalate did not, if a large excess of nitric acid were avoided.

The absence of chlorides, the careful proportioning of the reagents, and the concentration due to the use of solid chemicals favoured a complete separation of the phospho-molybdate free from tungsten, arsenic, or other interfering elements.

Detailed Procedure for Nickel-Chrome, Chrome-Tungsten, or Chrome-Tungsten-Vanadium Steels.

Digest 2 grammes of sample in a covered 400 cubic centimetre tall-form or conical beaker in 30 cubic centimetres HNO_3 (specific gravity, 1·22), or 33 cubic centimetres (specfic gravity, 1·20), till only a black residue remains and brown fumes are removed.

Add four compressed tablets (0·25 gramme $KMnO_4$ in each) whilst tilting the beaker, and boil gently for from three to five minutes. In rare instances extra $KMnO_4$ may be necessary if chromium exceeds 3 per cent. and tungsten 16 per cent.

If vanadium is absent add 1 compressed tablet [$(NH_4)_2C_2O_4$, 0·36 gramme; NH_4NO_3, 6·0 grammes] and three oxalic acid tablets (0·35 gramme each). This should clear the solution, and all but possibly a trace of black residue should disappear. (If any oxides of manganese still remain, add another oxalic acid tablet.)

Remove the beaker from the source of heat and at once add a cold mixture of 13 cubic centimetres concentrated ammonium molybdate solution (150 grammes per litre, faintly ammoniacal), mixed with 6·5 cubic centimetres HNO_3 (specific gravity, 1·42).

Agitate continuously for two minutes, and allow to settle at atmospheric temperature for at least two minutes, after which the phosphorus may be estimated in the yellow precipitate as usual either by washing with 0·1 per cent. KNO_3 and titrating with standard NaOH and HNO_3, or converting to lead molybdate, $PbMoO_4$.

If vanadium is present more ammonium nitrate is desirable for complete precipitation in the cold, so after digesting with $KMnO_4$ add two ammonium nitrate tablets and two oxalic acid tablets, and boil gently till the manganese oxides have dissolved.

(If it is desired to precipitate quickly by continuous agitation, it is better to add three ammonium nitrate tablets and one oxalic acid tablet, thus introducing an extra 6 grammes of ammonium nitrate.)

If vanadium is above 0·5 per cent. a slight "muddiness" sometimes remains, but this is removed later on.

Cool to 15° to 20° C., and add powdered ferrous sulphate till a ferricyanide spot test indicates excess, then add a further 0·25 to 0·5 gramme. This reduces the vanadium and avoids its interference. Precipitate in the cold with the same nitro-molybdate as before.

With occasional agitation, precipitation is complete within two hours, but it is convenient to allow to stand overnight; then estimate the yellow precipitate as usual.

Note 1.—Cold precipitation is sometimes preferable for high tungsten steels not containing vanadium, but if vanadium is absent, ferrous sulphate is of course unnecessary.

Note 2.—Sometimes a few milligrams of tungstic acid separate out during the process of solution and oxidation, &c. If this occurs the solution should be filtered, washed with 2 per cent. nitric acid water, avoiding dilution of the filtrate beyond 75 cubic centimetres, and precipitated *in the cold* (whether vanadium is present or not). With a few tungsten steels the dilution caused by filtration and washing causes more tungstic acid to separate when the nitro-molybdate is added. In these cases, repeat the analysis on 2·80 grammes instead of 2 grammes, using proportionately more acid and reagents, and after the ammonium nitrate tablet has cleared the solution, make up to 70 cubic centimetres, filter through a dry paper, measure 50 cubic centimetres of the filtrate (equivalent to 2 grammes of the steel), and precipitate as usual *in the cold*.

Note 3.—Whenever phospho-molybdate is precipitated at a low temperature, it is more soluble in the washing solution than if precipitated at 60° to 80° C. In warm weather, therefore, the washing solution should be cooled in tap water, or by other means, to 15° C. or less. About five small washes with 0·1 per cent. KNO_3 solution (when filtering through pulp) are sufficient to remove all acid.

The AUTHORS wrote in reply that they wished to thank Messrs. Etheridge and Ridsdale for their contributions, which confirmed their work.

A similar method to that described had been used by one of the authors some years ago, but the confusion that was made apparent by a perusal of the literature prompted a thorough examination of the method, and the present paper was the result.

The authors did not recommend prolongation of the baking beyond the short time necessary to get rid of fumes and to complete the oxidation of the phosphorus.

In the earlier work the solution of the steel was evaporated to a paste, as recommended by Mr. Etheridge, but it was found that oxidation of the phosphorus was, in some cases, not completed, and that slight baking was therefore necessary. In addition, baking tended to improve the separation of the tungstic acid from the iron solution; the amount of phosphorus retained by the tungstic acid did not appear

to be increased greatly by that treatment. The increase in retained impurities, mainly iron, was not disadvantageous.

The authors agreed with Mr. Etheridge that in the case of low-phosphorus steels, practically all the phosphorus was retained with the ferric hydroxide when the tungstic acid residue was dissolved in ammonia. It was necessary, however, before proceeding with the estimation of the phosphorus, to separate the small amount of tungstic acid which was also retained. They preferred to regard the phosphorus retained by the tungstic acid as combined rather than occluded.

They were glad that the results obtained by Mr. Ridsdale on their samples were in good agreement, except in the case of sample W, where a little tungstic acid had been carried down, as explained by Mr. Ridsdale. They hoped to try his method at some future date, he having kindly provided them with some tablets for that purpose.

In Note 2 of Mr. Ridsdale's method it was recommended that if a little tungstic acid should separate out, it should be filtered off. The authors wished to emphasise that a considerable proportion of the phosphorus might be carried down in such cases, and steps should be taken for its recovery before proceeding with the estimation.

THE REDUCTION OF FERRIC OXIDE AND IRON ORES BY HYDROGEN.

By H. KAMURA, M.Sc.
(Meiji College of Technology, Tobata, Japan).

AUTHOR'S REPLY TO CORRESPONDENCE.

In reply to Mr. Ralph C. Whitfield's correspondence on the subject of his paper (see *Journal of the Iron and Steel Institute*, 1925, No. II. pp. 279–298), Mr. H. Kamura wrote that he had long been aware that the reducing action of carbon monoxide on the metallic oxides was much stronger than that of solid carbon at low temperatures, and that its reducing action was not limited to the contact surface of the oxides as was carbon, owing to its diffusion. Some years ago he had started an investigation along that line, as he thought it might be possible to devise a method of direct reduction by the gaseous reducing agent for the production of soft iron and steel. He had read a paper on the reduction of iron ores by carbon monoxide before the American Institute of Mining and Metallurgical Engineers in February 1925.

The primary purpose of the present investigation was to throw light on the influence of hydrogen, which came from the moisture or hydrocarbons in the fuel, on the reduction. The experiments showed that the reducing action of hydrogen took place at a much lower temperature than that of carbon monoxide, and that the reduction was much easier for large sizes of ore, up to 1 centimetre size having been tried, so that, if cheap hydrogen were available as a by-product in some chemical industry, it might be possible to apply the process commercially.

If the reduction of iron ores were carried out in a temperature range of from 700° to 1000° C. by the mixture of carbon monoxide and hydrogen, as suggested by Mr. Whitfield, both gases would have an influence on the reduction, and the resulting gas mixture would consist of CO, H_2, CO_2, and H_2O, in proportions necessary for the chemical equilibrium of the gases at a given temperature. The reaction, $CO_2 + H_2 = CO + H_2O$, was known as the water-gas reaction, and had been frequently studied by several investigators. The equilibrium constant, $(CO)(H_2O)/(CO_2)(H_2) = K$, increased with the temperature. That was to say, in that case the change of CO_2 and H_2 to CO and steam was accompanied by an absorption of heat; consequently a rise of temperature would increase the proportion of CO and H_2O and decrease the proportion of CO_2 and H_2 in the gases which were in equilibrium. He thought, therefore, that the total reducing influence of the hydrogen and carbon monoxide in the gases on the iron oxide would not change, but with the higher proportion of hydrogen a lower temperature of

reduction would be used. He had used a carbon monoxide gas containing under 5 per cent. of hydrogen, but he could not find any marked influence. He agreed that the high proportion of hydrogen in the gas, such as Mr. Whitfield suggested, would have a beneficial effect on the reduction, and it was very important to keep the CO_2 as little as possible in the gases. The production of the gases by using oxigenated air and the economical lowering of the percentage of nitrogen would be a step nearer the attainment of the direct reduction of iron ore.

ANNUAL DINNER.

The Annual Dinner of the Institute was held in the Princes Room, Connaught Rooms, on Thursday, June 3, 1926, the President, Sir W. Peter Rylands, occupying the Chair. Among those present were Mr. Arthur Michael Samuel, M.P., Minister for the Overseas Trade Department; His Excellency Baron Palmstierna, G.C.V.O., Swedish Minister Plenipotentiary in London; Mr. Emil Kinander, Director of Jernkontoret, Stockholm; Sir Sydney Chapman, K.C.B., K.B.E., Permanent Secretary to the Board of Trade; Sir Hugh Bell, Bt., C.B., Past-President, Bessemer Medallist; Sir William Ellis, G.B.E., D.Eng., President of the Institution of Civil Engineers, and Past-President of the Institute; The Hon. Sir Charles Parsons, K.C.B., F.R.S.; Mr. A. Grabe, of the Technical Staff of Jernkontoret, and Hon. Secretary of the Stockholm Meeting; Sir William Larke, K.B.E., Director of the National Federation of Iron and Steel Manufacturers; Sir Joseph Petavel, K.B.E., F.R.S., Director of the National Physical Laboratory; Sir Robert Hadfield, Bt., F.R.S., Past-President; Sir Frederick Mills, Bt., D.L., Past-President; Mr. M. Mannaberg, Vice-President; Professor H. C. H. Carpenter, F.R.S., Hon. Treasurer; Mr. S. Frisell, representative of the Grängesberg Oxelösund Company; Mr. G. Montfort, representing Messrs. Schneider & Cie, Le Creusot; and many of the other Vice-Presidents and Members of Council.

The usual loyal toasts were proposed by the President and duly honoured.

The President said he thought the Iron and Steel Institute had never held its dinner on the occasion of His Majesty's birthday before, and he proposed that the company present should concur in sending to His Majesty a complimentary telegram of congratulations. That was cordially agreed to, and a telegram was forthwith despatched, to which later a gracious reply was received.

Sir Hugh Bell, Bt., C.B., in proposing the toast of "His Majesty's Ministers," said the Iron and Steel Institute had no politics, although individual members of the Institute were at liberty to hold any opinions they pleased—within certain limits.

Although the Institute was essentially British in its constitution, it was cosmopolitan in its members, and persons might hold any views as to the government of the State under which they lived, and they might even go to the extent of holding views as to the government of States in which they did not live. There was, however, one factor which might be claimed for all, and that was a profound respect for law and order. It was in that sense that they were proud to welcome at their table year after year representatives of the Government. The Institute had had the pleasure of proposing the health of emperors and presidents and kings and others, and had always done it wholeheartedly, because in every case the members knew that what they were really doing was proposing the health of orderly, regular government. Therefore, when the President was good enough to entrust to him the proposal of the present toast, he had no hesitation in accepting the honour, and he had great pleasure in inviting the meeting to drink to His Majesty's Ministers, coupled with the name of a distinguished member of the Government who was present that evening, Mr. A. M. Samuel, of the Department of Overseas Trade. He hoped he might be pardoned for venturing to suggest to the Minister charged with overseas trade that what was required most from Government was that people should be let alone. The judicious exemption from Government interference was that which members of the iron and steel trade, and of almost every other trade, desired most. Perhaps he was treading on rather dangerous ground, because he could hardly imagine what functions of overseas trade were discharged which would not involve some transgression of those limits which he was endeavouring to lay down. Therefore, in proposing Mr. Samuel's health, he had to do so with considerable discretion and with some delicacy. He should be sorry to say he thought the functions he discharged were discharged in any other than the most perfect way possible. He felt that, Mr. Samuel having been put in

that position, he would be extremely discreet in the way he discharged the duties of his office. In recent years we had suffered, and he thought we were still suffering, very seriously from a malinterpretation of the functions of government by those who had been put in charge. Looking back over a period of more than thirty years, he had come to the conclusion that if every statute which had been passed regarding the coal trade in that time had been omitted from the Statute Book, we should probably not be undergoing a coal strike to-day. That was a fairly good example of what was disliked in Government. What they liked of Government was that it should maintain order, and he thought it might be said of the present Government that it did discharge that function with extraordinary skill and firmness. What, in another country, might easily have been the beginning of a struggle of a most serious kind was at once taken hold of in a manner which showed, in the first place, the power of the Government and, in the second place, the loyalty of the people. Those two things converted what might have been a very serious time in English history into a further illustration of the extraordinary power of self-government possessed by the British people. While he was glad to think there was a Department of Labour and a Board of Trade and an Overseas Trade Department, what he most desired those departments to do was to look on with favourable eyes, ready to help industry when that help was required. He was glad to say to their distinguished guests that evening that he thought they were doing that to a large extent. He hoped it would be understood that his remarks were not intended to be taken at the "foot of the letter" entirely, but were to be regarded as more appropriate to an occasion of the present kind than to a conference at which, for example, the exact relations between the coal owner and the men in his employment and the landlord who drew the royalties and the State who claimed to say what had to be done—it was not a conference of that kind.

He asked those present to drink the health of Mr. Samuel, who was in charge of the Department of Overseas Trade, and he expressed the hope that he would do as little harm as was possible.

Mr. A. M. Samuel, M.P. (Department of Overseas Trade), in responding, said that, if the members were to examine their minds when they drank the health of H.M. Ministers, what really was uppermost was a most sincere wish that the health and strength of the Prime Minister might be preserved to carry on the work to which Sir Hugh Bell had referred. Although the task of replying to the toast was entrusted to him, he felt he must join with those present in wishing good health to the Prime Minister for the way in which he had handled the very difficult situation through which the country had passed. He had handled it in such a way that no malice or ill-feeling had been left behind, and it was to be hoped, when the coal dispute was settled, the same thing might be said. He was probably expected to say something about coal, but he thought it was better to hold his tongue, for fear he might say something which might affect the Government and reduce the chances of success in bringing about peace in a way that left no sting behind. But whatever remedies might be necessary for meeting the immediate difficulties, in the long run the success of the coal industry, and of all industries, could only be assured by loyal and efficient labour working hand-in-hand with sympathetic managers, the use of up-to-date equipment, and a wideawake selling organisation. He did not propose to say much about labour and management; but the use of modern equipment and an active selling organisation depended on the ingenuity of technical experts and the individuality and initiative of business men. Daniel Defoe said that Englishmen improved everything but invented nothing, and in that there was a certain degree of truth. The political institutions of the country had gradually evolved and were not the outcome of sudden and violent changes. But, so far as industry was concerned, the statement was not true, even in Defoe's time. Certainly, during the past 200 years, Englishmen had contributed their full share, and Sir Robert Hadfield was a living proof of what the men of this country had done and were still doing in the field of industrial invention and research. It was equally certain that, in commercial enterprise, the country led the world during the past century, and he was confident that, once the dispute in the coal industry was settled, Great Britain would again take her old

predominant position in world trade. Members in the iron industry should think of the vast market which must some day be opened up in China, a country of over 400 millions of people, where at present in every 1000 square miles there were only two miles of railway as against over twenty in India, which itself had still vast opportunities for extension. Of the increased world demand Great Britain would claim her share if only equipment and knowledge were kept up-to-date and there was no failure at the selling end. In the heavy engineering trades especially there was need for the man on the spot, who, by personal contact with potential customers, was able to arrange products to meet local requirements.

If this country was to remain at the forefront, increased attention had to be given to research. It was recently suggested that in Great Britain, which could claim credit for most of the important discoveries—taking only the iron and steel industry, the names of Huntsman, Nasmyth, Gilchrist-Thomas sprang immediately to one's mind—the general public had very little appreciation of what research could do, and he was afraid that was equally true of a good many of the industrialists who benefited directly from the fruits of research. A cynic, speaking of the research work in one of the leading industries, recently told him that, as far as he could see, the energies of the research workers were of necessity still devoted more to the discovery of financial support than the research of scientific truths.

The iron and steel industry, and the industries depending upon it, formed a group second to none in importance in this country. The industry could make claims almost as sweeping as those which he happened to notice in a book written seventy years ago on Industrial Progress, in which the writer said: "Great and mighty interests were involved in the continued advancement and prosperity of the iron trade. By her iron and machinery Great Britain was working out not only her own redemption, but the redemption of the world from political slavery and social and moral degradation." As a matter of fact, the abolition of slavery might be associated with the rise in the iron and steel industries. In early times the only way to avoid labour was to impose the labour on someone else. Wealth and ease then depended on the increasing numbers of those who could be

compelled to toil on one's behalf, not as now on the increasing efficiency of methods of production. With the invention of machinery the demand for slaves fell off. As iron and steel supplanted human labour and brought about industrial revolution, Britain led the way to abolishing slavery within the British Empire.

In two other industries recent Exhibitions had shown what British enterprise and knowledge could do. There had taken place in the artificial silk industry a transformation which would rival the dreams of the old alchemists, a transformation from blocks of wood to beautiful fabrics. In optical apparatus progress had been such that British products were now equal in quality to anything the world could show. The iron and steel industry had had the same enterprise and imagination which led to discovery. Sir Hugh Bell did not see eye to eye with the Government. Sir Hugh Bell and he would not find much about which they could agree regarding the proper functions of Government in relation to trade, for Sir Hugh held that there were none, that Governments should simply keep out of the way. In some cases he wished that were possible, for it was depressing to find on what matters some traders now looked to the State for guidance, and perhaps assistance. He supposed it was because the relatively easy success achieved fifty years ago had probably lulled the British exporters into a sense of security. In some markets this country had in recent years been outstripped by energetic pushing at the selling end by the merchants of countries which had more recently entered the world-market. It was in salesmanship rather than in scientific knowledge and equipment that this country was in danger of falling behind. It was only necessary, however, to realise the danger in order to call forth the effort to defeat it.

So far as India was concerned at the actual moment, and China when conditions there had become more settled, he recommended the heavy engineering trades to make a point of strengthening their existing overseas agency methods of sale. From information that had reached him from the Department of Overseas Trade he was convinced that, in addition to advertising, the policy of firms should be one of personal contact on the spot with customers through their own representatives who under-

stood the goods they had to sell and who had power to vary the patterns and the terms of contract. He hoped he had not been too dogmatic, but he spoke not only as a Minister but as one who had to earn his living in the export trade. He thanked those present for the kindly toast, and could assure them that whatever their efforts might result in, H.M. Government would leave no stone unturned to support any methods to increase the trade of the country, and the Department of Overseas Trade, above all, was only too eager to help industry to help itself.

Sir Frederick Mills, Bt., D.L., in proposing the toast of "The Guests," said the toast that had been put into his hands was an unaccustomed one to him, as he was generally given something upon which he could speedily branch out into protection, or something of that kind, and he thought the toast had been placed in his hands so that he might be kept out of mischief. There were many distinguished people present, but, as charity began at home, he would take the home people first and start with the youngest, Sir Hugh Bell. (Laughter.) Sir Hugh Bell was an original member of the Institute, one of the two or three who were fortunately left. That morning the President had had the great honour of presenting Sir Hugh with a Bessemer Gold Medal, thus repeating after more than half a century the honour paid to his—he might say—even more distinguished father. There was also present Sir William Ellis, another of their members, who was a guest as President of the Institution of Civil Engineers. Sir Charles Parsons was also present. He knew Sir Charles Parsons, because when he was an apprentice on the Tyne, more than forty years ago, he had the honour of seeing his first turbine. There was also present Mr. Cyril Lloyd, who had been elected a member of the Council that morning. Sir William Larke, another member of the Institute, who was also a guest, had proved a tower of strength to the industry on its business side. There were also present members of the Government, including the Minister of Overseas Trade Department, and Sir Sydney Chapman, Mr. Carlton, and others, and he welcomed them all. But the principal guests that evening were those from the kingdom of Sweden (cheers), and he was asking the members to honour them. Those who had visited Sweden—and he had on several occasions—knew

that when the Institute went there in the autumn they would have a right royal welcome. It was necessary to go prepared.

There were present that evening Mr. Kinander, Director of the Swedish Ironmasters' Association, and also Mr. Sahlin, the Swedish Consul-General, and the Swedish Minister himself, His Excellency Baron Palmstierna. (Cheers.) They welcomed those gentlemen that evening, and assured them that the members were going to Sweden in vast crowds to enjoy the hospitality of which they were past-masters.

His Excellency Baron Palmstierna, G.C.V.O. (Swedish Minister Plenipotentiary), in responding, said he felt very much cheered by the kind applause given to him when the toast was proposed, and he had to respond on behalf of the guests. He felt that a great honour had been done to him in inviting him to the banquet and asking him to respond to the toast in such a distinguished assembly of representatives working in the field of iron and steel. He thought it could be said that iron and steel were at the basis of material civilisation; they were at the foundation of that wonderful society which embodied so much of human progress and of civilisation. While listening to Mr. Samuel, he thought that it was not only gold that could be reached through iron; it was possible to acquire that power over Nature which brought them into touch with all the higher spheres of life. That wonderful society of ours had been built up of iron and steel, and he could see no change in that respect at present. Iron would, so far as he could perceive, remain the foundation for paving new roads to prosperity for an increasing number of human beings, and it looked, as a matter of fact, as if the nations would become more dependent on iron and steel as years went on. Therefore, to his mind, it was a great thing when nations could be brought to co-operate together and brought into closer relation in the particular field of work connected with iron and steel, and it could truly be said that no closer or better relations existed between two nations than that between the British and Swedish. (Cheers.) It was not necessary to be a metallurgist to know the quite unique relations which had existed, and still existed, between those two nations with regard to iron and steel. Not only was there an important interchange of the products of the iron industry, but there

was also, and had been for many years, an interchange of thoughts and ideas of scientific and practical results which he felt certain would continue. Sweden was a very old iron country, and once held the leading place in the world in the production of iron. Between the years 1720 and 1740 Sweden made twice as much iron as Great Britain, and even as late as 1780 the Swedish output exceeded that of this country, and was still the largest in the world. All that took place before the days of the puddling process, which made it possible to use coke in smelting, and then, by the introduction of other methods and the general development of the world, Sweden had to give place to others, and Great Britain was the first to step into the favoured place, and Sweden did not grudge her doing so. In Sweden, naturally, several changes in the process of the manufacture of iron and steel had taken place during the passing of the years, and it was interesting to know that what was called the British-Lancashire hearth was introduced with the aid of British workmen about 1820. Not only had Swedish iron played a great part as raw material in the manufacture of finished articles in the great industrial countries abroad, but also it had been a great boon to the small blacksmith and the humble husbandman in the more primitive countries.

To his great surprise he had heard from Mr. Samuel that someone had said that Englishmen were good at improving things but not at making new inventions; but he demurred to that and could give a few proofs of how incorrect the statement was. Crucible steel was not now manufactured to any great extent in Sweden, but when it was first taken up it was the Huntsman process, which was employed by a Swedish metallurgist who had visited England and returned to Sweden with an enterprising Scotsman by the name of Thomas Lewis, who supervised the erection of the works. The Scots had not only helped them in their successful wars, but had been with them in the more peaceful fields of life. Then, of course, in later years there was another British invention which was transplanted to Sweden, the Bessemer process, but it was a rather incomplete form of development, and it was Göransson, the founder of the Sandviken Steelworks, who first succeeded in turning into a practical success the process which had since meant so much to the iron and steel industry of the world. The names of those persons who had played a

prominent part in the work during latter years were, of course, well known and need not be enumerated, but there was one other name he would like to mention, and he could not let the occasion pass without a reference to the grand old man of Swedish metallurgy, Mr. Brinell. Great Britain was not such a large consumer of Swedish ore as certain other countries, but the quantities discharged at British ports were not inconsiderable. The development of Swedish phosphoric ore resources was in a great measure due to the farsightedness and initiative of a British banker, Sir Ernest Cassel. Those incidents were only a few that he could give in the short time at his disposal of the close and intimate relations which for years had been existing between the two countries in the field of iron and steel. Those relations between the Swedish iron trade and the British iron trade had existed for more than 200 years. He was now happy to gather that a renewed effort would be made to tighten the bonds of friendship and collaboration between Sweden and Great Britain by the Institute sending representatives over to Sweden, on the invitation of the Swedish Ironmasters' Association, which since the middle of the eighteenth century had played such a great and leading part in promoting the development of the Swedish iron industry and in bringing its products to a high standard of quality. At present there was a depression in the iron trade in Sweden, and efforts were being made, although without immediate success, to concentrate the big ironworks on a more national basis; but he believed that there would be sufficient objects of interest for those of the members who were going over, and he could say that Sweden had, since they visited the country years ago, made great strides in advancing her high standard of civilisation. The members when they came to Sweden would not only come in touch with leading people in the iron and steel trade, but would meet men who, in different respects, were the leaders of Sweden of the present day—animated by a strong spirit of enterprise and of ideals. Nothing could be of greater pleasure than to bid the members of the Institute, although it might seem a bit early in the day, a great welcome to the old iron land. The last visit was still cherished as a happy memory, and he was sure, on the return of the members from Sweden in the autumn, they would be saying to themselves that they had met the Swedes as they only met real friends and good comrades.

Mr. E. Kinander, in saying a few words at the request of the President, said that after the speech of his old friend Baron Palmstierna there was nothing left for him to say. He had been asked to renew in the name of the Swedish Ironmasters' Association the invitation already accepted by the Iron and Steel Institute to hold their autumn meeting this year in Stockholm, and he hoped that the meeting would be a truly successful one. He hoped the members would take part in large numbers in the meeting at Stockholm next August.

Sir Sydney Chapman, K.C.B. (Permanent Secretary, Board of Trade), in proposing the toast of the Institute, said he esteemed it a great honour to have been selected to propose it, but at the same time he felt a certain amount of trepidation in speaking as an official when one of the Ministers of the Crown had spoken. The remarks of that Minister had shown how close was the cordial relationship between the officials who were the navigators and the Ministers who were the captains. He found that the Institute was founded in the year 1869, and he was going to suggest that it was founded then because it was prophetically realised that in the previous year there had been a birth which assured to the Institute that it would have a distinguished President when it attained its prime some fifty odd years later, the President having been born in 1868. The Institute had done notable service for the iron and steel industry, and if that industry was to recover its earlier prosperity the Institute had still to do a great work. The problems of industry were extremely difficult, and in no industry were they greater and more complicated than in the iron and steel industry. There were many factors. There was the purely scientific and technological, and the problem of industrial organisation involving mass production, and labour problems and marketing problems. He suggested that success in the art of industrial management depended very largely upon what might be called timing in dealing with the various problems, a term which was taken from golf. The problem of adjustment was not unlike that of golf, the difference being that in industry it was soluble and in golf the problems were insoluble. The place taken by Great Britain in early years in the iron and steel industry was due to the solution of the scientific problems, to the discoveries of Cort and others. It was a great personal

pleasure to him to see at the table a very old friend of his, a descendant of Cort, Henry Cort Carpenter. It was not for him to say which problems to-day were of the greatest importance, but he was convinced that the scientific one was not the least. Wherever there was a question of scientific problems one discovered at once Institutes, Associations, Societies and Corporations of some kind, and he had been reminded that Adam Smith demonstrated that in exchange it was a fallacy to suppose that there was a certain pile which was limited and so shared out that if one person benefited in exchange another must lose. The Chancellor of the Exchequer, in his speech at the Government Dinner to the International Parliamentary Commercial Conference, developed that idea, and argued that in international affairs it must not be thought that there was a pile of prosperity so finite in character that if one country prospered it must be to the loss of another. All that was very true, but most true of knowledge, as members of the Institute would realise. Everybody connected with the pursuit of knowledge knew that knowledge was not to be thought of as a limited pile of such a kind that the individual of talent best served himself who took for himself what he could get. Knowledge was a pile of such a kind that when it was pooled the pool was infinitely greater than the aggregate of what each individual put in, and therefore what each individual obtained was far greater than what he put in. That was why the Institute was formed, and he was convinced it was going to play a great part in the restoration and the prosperity of the British iron and steel industry. He gave the toast of the Iron and Steel Institute knowing the great value of its future work, coupled with the name of the President, Sir Peter Rylands.

The President, in reply, thanked the members for the manner in which they had received the toast. He could not help feeling that it was a very appropriate and pleasant thing for a representative of the Government to propose a toast of the kind, and it was also very pleasing to have a prominent representative of the Government, such as Mr. Samuel, taking part in the proceedings. One might agree to some extent with Sir Hugh Bell as to the inadvisability of too much Government interference, but one could not get away from the fact that after all a great industry

like that of iron and steel was one of the foundations by which the British people were supported, and consequently its well-being could not be altogether a matter of unconcern to H.M. Government. While there might be a limit to the extent to which the Government themselves could help, it was of very great moment that the Government should try and acquire a little first-hand knowledge of the industry and satisfy themselves as to how far those responsible for its conduct were discharging their stewardship. He was afraid it was unfortunately true that the British people were rather inclined to belittle themselves ; they were never tired of drawing attention to their shortcomings. It was true they resented any such thing in the mouths of others, but so far as they themselves were concerned it was a British privilege to criticise themselves, their fellow countrymen, and particularly those who were set in authority over them. It was, however, pleasing sometimes to look on the other side of the picture and see that the British people, after all, were not so inefficient and so hopeless as they were sometimes supposed to be. He sometimes thought that a criticism such as Mr. Samuel made in regard to sales organisation was not altogether without some foundation. Other nations formed great aggregations and combinations and were able to develop an expensive sales organisation throughout the world, which was not possible with men pursuing their industry with too high a degree of individualism. He believed the British people were learning a lesson, and those in the Iron and Steel Institute at all events were doing their best to pool their brains. He believed there was an increasing tendency for the barrier of individualism to break down, a tendency to realise that co-operation in the widest sense was the best for all, that by working together there was more likelihood of achievement than by working separately. He believed the Institute had performed a great work in the past and was inspiring its members with a sentiment which was particularly appropriate to the time, and he hoped that in that spirit of co-operation it would be possible to find some way out of the undoubted difficulties under which the industry of the country was labouring at the present time.

OBITUARY.

Charles Paxton Markham, *Member of Council*, died suddenly at his residence on June 29, 1926. He was the eldest son of the late Mr. Charles Markham of Tapton House, and was a grandson of Joseph Paxton. He held a very important position in the mining industry, and enjoyed a considerable reputation on account of his independence of outlook on industrial questions. He was a strong individualist, and always remained outside the Coal Owners' Association, notwithstanding that he was associated with the management of a large number of collieries in the Nottingham and Derbyshire area. He was of a very enterprising nature and endued with progressive ideas, both as regards the social welfare of the workers in his undertakings and the equipment of his pits and works. In his latter years most of his time and energies were devoted to the development of the Staveley Coal and Iron Co., Ltd. He took a considerable interest in local affairs, having been High Sheriff of Derbyshire in 1913–14, twice Chairman of Quarter Sessions, and three times Mayor of Chesterfield. A few years ago he presented Tapton House and Park to the town of Chesterfield, and his benefactions in many directions were on a princely scale. Mr. Markham was elected a member of the Institute in 1890, and a Member of Council in 1923. His hospitable entertainment of the members at Parkgate and Staveley on the occasion of the Autumn Meeting of the Institute at York will still be within the recollection of many who attended that meeting.

Johan August Brinell died on November 17, 1925. He received his early education at Jönköping, and afterwards attended the Technical School at Borås. In 1875 he obtained a position as engineer with G. Ekman, engineer at Lesjöfors, and it was here that he became associated with the Swedish iron industry, to which the remainder of his life's work was devoted. In 1882 he accepted the position of chief engineer to the Fagersta Ironworks, which he filled with remarkable success, and it was here that he carried out the comprehensive series of investigations, the results of which established his reputation throughout the scientific world. He remained at Fagersta until 1903, in which year he was invited to accept the newly created office of Chief Engineer of Jernkontoret, which he held until 1914. It was, however, at Fagersta that he developed the genius he possessed. His first studies were concerned with the changes which take place in steel when heated, a subject which up till that time was little understood, and as the result of his investigations he published a paper in *Jern-*

kontorets Annaler on "Changes in the Texture of Steel during Heating and Cooling," in which he presented a scientific explanation of the phenomena observed in the heating and cooling of steel. His views were accepted by iron and steel metallurgists throughout the world, and the paper has since been regarded as a classic on the subject. Brinell then directed his studies to determining the hardness of iron and steel and other homogeneous bodies. At the Paris Exhibition in 1900 he demonstrated to the world, for the first time, his method for testing hardness and other physical properties of iron and steel, and the apparatus with which the determinations were carried out, and in 1901 a full report upon the determination of hardness by indenting the surface of a material by means of a steel ball loaded to a certain pressure was published simultaneously in *Jernkontorets Annaler* and the *Journal of the Iron and Steel Institute*. The report to the Iron and Steel Institute was compiled by Mr. Axel Wahlberg and presented in his name, and it was immediately republished in the technical papers of all countries. In recognition of the great importance of Brinell's investigations, which had led to results of such practical value, he was awarded the Bessemer Gold Medal of the Iron and Steel Institute in 1907. Later he published another memoir on "A Method for Measuring the Resistance to Wear of Iron and Steel and other Solid Bodies," and in recognition of the merit of this and of his earlier investigations he was awarded the Polhem medal of the Swedish Institute of Civil Engineers and the Rinman medal of Jernkontoret. He received the honorary degree of Doctor of Philosophy of Upsala University, and was honoured in other special ways. In 1913 he served on a Committee of the San Francisco Exhibition, and in 1916 he became Chairman of Fagersta Forge and of the Peat Fibre Co. of Nasjö. Honours were also bestowed upon him by His Majesty the King of Sweden.

He was elected a member of the Iron and Steel Institute in 1897.

Per Torsten Berg died at Stockholm on May 14, 1926, at the age of seventy-three. Mr. Berg was for many years Chief Engineer of the Carnegie Steel Company, Pittsburgh, and later was appointed technical representative in Europe of the United States Steel Corporation. In 1915 he was appointed United States Vice-Consul in Sweden. Mr. Berg was also a member of the General Reception Committee formed in Sweden early in 1926 for the purpose of entertaining the visiting members on the occasion of the Autumn Meeting of the Institute at the end of August, but his death unfortunately occurred before the meeting took place. He was elected a member of the Iron and Steel Institute in 1904.

Camille Cavallier died suddenly at Nancy, France, on June 10, 1926. For more than thirty years he had been managing director of the Pont-à-Mousson Cast-Iron Pipe Foundries, and also a director of many other important undertakings, being one of the leading figures

associated with the mining and iron and steel industries of France. His hospitable reception of a large party of members at his works at Pont-à-Mousson on the occasion of the meeting of the Institute in France in 1921 will long be remembered by those who were privileged to participate in the visit. Mr. Cavallier was elected a member of the Iron and Steel Institute in 1903.

Robert Hobson died in February 1926 at Hamilton, Ontario. Mr. Hobson was born at Kitchener, Ontario, in 1861, and after completion of his education he became engaged in railway work. He afterwards turned his attention to the development of the iron and steel industries of Canada, and became one of the most prominent industrial pioneers in the Dominion. He was general manager and vice-president of the Steel Company of Canada from 1910–15, and in the latter year became president of the company. During 1908 he held the presidency of the Canadian Manufacturers' Association. He was elected a member of the Iron and Steel Institute in 1921.

Cecil Harold Hoskins died in April 1926. He was born in London, but emigrated when quite young with his parents to Australia. At the age of twenty-five he started an engineering business in Sydney in company with his two brothers, taking up the manufacture of engines, boilers, and steel water-pipes. In 1908 he took over the Lithgow Ironworks, the most important works manufacturing iron and steel in Australia at that time, which underwent great developments under the direction of Mr. Hoskins and one brother. In 1919 Mr. C. H. Hoskins bought up the whole of his brother's interest, becoming the sole proprietor of the business. He was elected a member of the Iron and Steel Institute in 1920.

James Rossiter Hoyle died in London on March 14, 1926. He was born in Manchester, where his father held an important appointment in the firm of Messrs. Armstrong, Whitworth. He received his early education at Owens College, and subsequently entered the firm of Messrs. Bury & Co., a Sheffield steel-making firm, under the management of his brother-in-law. Later he was engaged as engineer in Paris, and through business interests came into touch with the firm of Thomas Firth & Son, who had secured a contract with the French Government. Mr. Hoyle went to Sheffield about the year 1881, and was for some time manager of Firth's Gun Works. In 1885 he built the company's steel plant in Sheffield. In 1893 he became a director of Thomas Firth & Sons, and when his co-director, Mr. Lewis J. Firth, went to America to organise the Firth Sterling Steel Co. in Pittsburgh, Mr. Hoyle assumed the entire directorship of the Sheffield works. He became managing director of the firm, from which position he retired at the end of 1921. In 1912 he was Master Cutler of Sheffield. He was elected a member of the Iron and Steel Institute in 1884.

Isaac E. Lester died at his residence at Edgbaston on November 27, 1925. Mr. Lester, who was the son of a former manager of the Monway Works and of the Patent Shaft and Axletree Co., Ltd., received his early training at the Midland Institute, Birmingham, and at the Royal School of Mines. He made a special study of foundry work, and eventually was appointed manager of the foundry of Kynochs Ltd. He afterwards proceeded to India, for the purpose of establishing a foundry for the East India Railway Co., where he produced castings for the first locomotives built in India by the company. After his return to this country he became manager to Charles Akrill & Co., Ltd., ironfounders, of West Bromwich, and subsequently became managing director of that firm. He was a past-president of the Birmingham Metallurgical Society and of the Staffordshire Iron and Steel Institute. He was a constant attendant at the meetings of the Iron and Steel Institute, and on the occasion of the Birmingham Meeting in 1925 he was a member of the Executive Committee, giving valuable assistance in organising the arrangements for the Meeting.

He was elected a member of the Institute in 1899.

Giuseppe Orlando died at Rome on January 27, 1926, after a long illness. He was born in Genoa on February 8, 1855, and at the age of seventeen entered the Royal Naval School at Genoa, from which he graduated as Mechanical Naval Engineer in 1877. He then joined the staff of the naval shipyard at Leghorn, one of the very few in Italy, and the first work which he supervised was the construction of the merchant vessel *Venezia*, and afterwards the armoured vessel *Lepanto*, which at that time was the largest warship of the world. After 1890 he became associated with the Terni Co., of which he was president and managing director for many years. In 1906, in co-operation with his colleague Odero, he founded the Vickers Terni Co. at Spezia, which played so important a part in the national defence during the Great War. In 1919 he took over the management of the Quarnaro Shipyard, and subsequently the Whitehead Torpedo Factory, near Trieste. He was associated with the development of many other mining and engineering enterprises in Italy, and in recognition of his public services he received the decorations of the Cross of Grand Officer of the Crown of Italy, and of the Cross of the Knights of Labour. He was elected a member of the Institute in 1917.

Thomas William Ward died at Sheffield on February 3, 1926. He was born in that city in 1853, and in his early years was associated in business with his father. Later he started business on his own account, and was one of the first to realise the possibilities in connection with the utilisation of scrap metal. He began to purchase scrap iron and steel in small quantities at first, and as his business prospered his dealings ultimately developed on a very large scale. He bought up warships and other obsolete vessels, which he dismantled

and broke up, his activities extending to many parts of the United Kingdom, until the operations of Messrs. T. W. Ward, Ltd., embraced almost every branch of engineering. Mr. Ward was elected Master Cutler in 1913, and for the years 1912–13 he was president of the Sheffield Chamber of Commerce. He was elected a member of the Iron and Steel Institute in 1897.

SECTION II.

NOTES ON THE PROGRESS OF THE HOME AND FOREIGN IRON AND STEEL INDUSTRIES.

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The Editor has been assisted in the preparation of these Notes by R. Elsdon, Librarian of the Institute.

IRON ORES

AND OTHER METALLIFEROUS ORES USED IN THE IRON AND STEEL INDUSTRY.

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I.—*GEOGRAPHICAL DISTRIBUTION OF ORES.*

(Arranged in alphabetical order under Countries.)

Africa.—*Algeria an Important Iron Ore Source* (Iron Age, Apr. 8, 1926, vol. 117, pp. 986–987). Brief particulars are given of the iron ore resources of Algeria. The Ouenza mine is the largest and most important, and is situated on the north coast. It is operated by the Société de l'Ouenza, a French Company. The ore is a red hæmatite of the following composition: Iron, 56·19; manganese, 1·90; silica, 1·67; phosphorus, 0·006; silicon, 0·085; and copper, 0·05 per cent. Other mines being developed are: the Bou Kadra mine, about 12 miles from the Ouenza mine; the Timezrit mines, near El Maten; and the mines of Yebel Zaccar, near Milianah. A small deposit of manganiferous iron ore, known as Rar-el-Maden, the manganese content of which is from 6 to 8 per cent., occurs near the Moroccan frontier.

R. A. Farquharson, *First Report on the Geology and Mineral Resources of British Somaliland* (London, 1924). An account is given of the general and economic geology of the Protectorate. Included in the minerals of industrial value which have so far been found are the following: Coal, lignite, petroleum, molybdenite, manganese ore, and graphite.

A. E. Kitson, *Outlines of the Mineral and Water-Power Resources of the Gold Coast, British West Africa* (Gold Coast Geological Survey, 1925, Bulletin No. 1). The mineral deposits of present economic value comprise gold, manganese, and aluminium ores, and diamonds. The principal mineral is bauxite, which occurs in very large deposits of high quality. Manganese ores have been found in several places in the Gold Coast. The chief deposits are at Insuta and Dagwin. A large proportion of the Insuta and Dagwin ore is of high quality, specially

suitable for the manufacture of ferro-manganese. Much of it is used in the chemical industry. The analysis of the average ore is as follows :

	Per Cent.
Manganese	50–53
Iron	2–4
Silica	3–7
Phosphorus	0·1–0·12

The Insuta-Dagwin deposits are being worked by the African Manganese Company, and the present output is about 360,000 tons per annum. Other minerals found in the colony include iron, tin, copper, and titanium. A section of the report is devoted to the potential hydro-electric power in the country, for the electric smelting of aluminium ore and for various other purposes.

Chromite in South Africa (South African Engineering and Mining Journal, July 11, 1925, p. 539). Particulars are given of the chromite deposits in the Rustenburg District, Transvaal. There are at least three parallel lodes about 1½ miles apart, the outcrops of which can be traced from Rustenburg for 60 miles. The lodes are from 7 to 40 feet wide, and contain from 38 to 48 per cent. of chromic oxide.

G. Castelli, *Mineral Deposits of Portuguese Angola* (Rassegna Mineraria, 1925, vol. 62, pp. 101–107, 125-131). The principal deposits include iron, copper, manganese, molybdenum, and titanium ores, and asphalts and lignites. The geology and the chemical and physical characteristics of the deposits are described, including analyses of the ores.

Australia.—H. G. Raggatt, *Chromite Deposits of New South Wales* (New South Wales Geological Survey, 1925, Bulletin No. 13). There are three serpentine belts which have produced chromite—the Gordonbrook belt, the Great Serpentine belt, and the Gundagai-Wallendbeen Serpentine belt. Ore from the Gordonbrook belt assays from 39·7 to 55·27 per cent. of chromic oxide, and the amount of ore obtainable is estimated at 20,000 tons. The main producing centres of the Great Serpentine belt are Nundle, Attunga, Manilla, Barraba, and Bingare. In Wallendbeen the average content of chromic oxide in the samples is 47 per cent.

Canada.—C. O. Swanson, *The Genesis of the Texada Islands Magnetite Deposits* (Canada, Department of Mines : Summary Report, 1924, pp. 106–144A). The probable conditions under which Fe_3O_4 was deposited from magmatic solutions are described.

V. L. Eardley-Wilmot, *Molybdenum* (Canada, Department of Mines, Mines Branch, 1925, Report No. 592, pp. 3–192). This report, which deals with the metallurgy, uses, and occurrence of molybdenum, contains an account of the ores of molybdenum and describes the occurrences and deposits of molybdenite in Canada. Molybdenite is widely distributed throughout Eastern Canada and British Columbia. Up

to the present, the main molybdenite-producing area has been almost entirely confined to a zone of Precambrian rocks, bounded on the south by the lower Ottawa Valley in Southern Quebec, and passing south-west through Renfrew county to southern Haliburton county in Ontario. Particulars are also included of the world's molybdenum deposits.

R. C. Wallace, *Mineral Deposits of Hudson Bay Territory* (Bulletin of the Canadian Institute of Mining and Metallurgy, Dec. 1925, No. 164, pp. 1165–1176).

Cuba.—O. R. Kuhn, *Iron Ore Deposits of Cuba* (Engineering and Mining Journal-Press, Apr. 10, 1926, vol. 121, pp. 607–610). It is estimated that Cuba's iron ore reserves amount to over 3000 million tons. The island has no iron industry, and practically the whole of the ore produced goes to the United States of America.

France.—O. R. Kuhn, *Lorraine Iron Ore Deposits* (Blast-Furnace and Steel Plant, Apr. 1926, vol. 14, pp. 158–161). A survey of the iron ore deposits of Lorraine. A table is given showing the composition of the ores derived from the various districts. The reserves of iron ore in the Lorraine Basin are estimated at about 5600 million tons —a figure which compares very favourably with other known large deposits. The ore is, however, low grade, varying from about 24 to 41 per cent. of iron; it is an oolitic hæmatite (minette), consisting largely of iron oxide with smaller amounts of ferrous carbonates, the matrix being either calcareous or siliceous. The phosphorus is high, and the ore is well adapted for making basic Bessemer pig.

Italy.—G. Castelli, *The Tre Monti Manganese Mines above Sestri Levante* (Rassegna Mineraria, 1925, vol. 63, pp. 101–103). The manganese ore is of chemical sedimentary origin and occurs in phtamite-jasper formations accompanying serpentine rock. The geology, methods of exploitation, and equipment of the mines are described.

Jugo-Slavia.—F. Czermak, *Two Iron Ore Occurrences of Marine Sedimentary Origin in Serbia* (Zeitschrift für Praktische Geologie, Nov. 1925, vol. 33, pp. 175–178). The geological character of some small oolitic iron ore deposits is described, with maps of the districts in which they occur. The iron content runs at about 40 per cent., with 2 to 3 per cent. Cr_2O_3, but the deposits have no great economic importance.

Newfoundland.—A. Hasebrink, *The Iron Ore Deposits of Wabana, Newfoundland* (Glückauf, May 1, 1926, vol. 62, pp. 553–561). The author deals with the geographical position and geological conditions of the Wabana ore deposits, and then gives particulars of composition of the ore, methods of mining, and of the ore handling and loading plant. The output is now about 1,100,000 tons yearly, of which some three-

quarters is exported to Germany and the remainder to Nova Scotia, with occasional small consignments to the United Kingdom and to the United States.

The Iron Ore Mines at Bell Island (Iron and Steel of Canada, Nov. 1925, vol. 8, p. 237). A short note on these mines owned by the Nova Scotia Steel Co. and the Dominion Iron and Steel Co. Six beds of ore have been located, but only three are known to be sufficiently thick to be worth working, and of these the upper one will probably not be mined until operations have been carried much further under the sea (Conception Bay). The other two are 8 and 12 feet thick and extend over a mile under the sea-bed ; it is estimated that these deposits will outlast all others in the world.

Norway.—C. E. Wegmann, *The Iron Ores of the Massives of Ytre Fosen in Norway* (Zeitschrift für Praktische Geologie, Feb. 1926, vol. 34, pp. 17–23). The author describes the geological features of the iron ores occurring in the rocks forming the outer part of the Fosen peninsula outside the Trondhjemfiord. The ores consist of magnetite, but no indication is given of their economic value.

Russia.—*Russian Manganese Deposit near Tuapse* (Mining Journal, Dec. 5, 1925, vol. 151, p. 958). The geologist Selsky reported recently on the newly discovered deposits of manganese in the Maikop district. They are situated about 40 versts from Labinsk, which is 200 versts from the port of Tuapse, whence convenient export should be possible. Two beds of considerable thickness have been found, one estimated to contain about 120 million poods and the other about 140 million poods. Analysis shows a percentage of manganese from 8 to 78 per cent., and, owing to the nature of the ground, production will be easy. The quality of the ore, so far, appears to be inferior to Nikopol and Tchiaturi, but superior to Brazilian and Indian.

South America.—O. R. Kuhn, *Vast Iron Ore Reserve in South America* (Iron Trade Review, Apr. 8, 1926, vol. 78, pp. 925–927). The iron ore deposits in South America are considered economically. The iron ore reserves are estimated at 8700 million tons. Typical analyses of South American iron ores and coals are tabulated.

Spain.—O. R. Kuhn, *Spain—The World's Oldest Producer of Iron Ore* (Engineering and Mining Journal-Press, Feb. 27, 1926, vol. 121, pp. 367–372). A review of the history and present status of the iron ore mining industry in Spain.

R. M. de Rotaeche, *The Present Position of the Mining Industry of Viscaya and its Future Prospects* (Revista Minera, Feb. 16, 1926, vol. 77, pp. 93–95). The output of iron ore in the Bilbao district, which was about 6 million tons in 1899, has only averaged about 2 million tons for the last few years, and the decline of the iron mining industry of

Viscaya has frankly to be faced. The reduced export is largely due to the great drop in prices, which are about 30 per cent. lower than in 1913, while the costs of mining have approximately doubled. Nevertheless, other industries in the province have grown up, and abounding prosperity is noted, notwithstanding the decline of the iron ore trade.

Transcaucasia.—V. C. Svimonoff, *Potentialities of Georgian Manganese* (Engineering and Mining Journal, Oct. 31, 1925, vol. 120, p. 690). A review of the conditions prevailing in Georgia, and of the methods employed in mining manganese ore, with an indication of the future prospects. The potential manganese reserves are estimated at between one and two hundred million tons. The mines have so far been worked by manual labour, but abundance of water-power is available, and its application should help to make mining still more economical.

United States.—T. H. Aldrich, *Notes on the Clinton Group in Alabama* (Transactions of the American Institute of Mining and Metallurgical Engineers, 1924–25, vol. 71, pp. 304–307). The author presents the records of a number of bore-holes drilled primarily for oil, but which show the presence of either ore or red rock, and suggest vast resources yet to be developed in this region.

A. H. Brooks, *Mineral Resources of Alaska*, 1923 (United States Geological Survey, 1925, Bulletin 773). This publication is the twentieth of a series of annual bulletins, and summarises the results achieved during 1923 in the investigation of the mineral resources of Alaska.

G. A. Thiel, *Phosphorus Iron Ores on the Cuyuna Range* (Engineering and Mining Journal-Press, Apr. 24, 1926, vol. 121, pp. 687–690). A geological review of the iron ores in the Cuyuna range, Minnesota, with notes on the experiments made to determine whether the high-phosphorus ores could be sufficiently beneficiated to make them available for the manufacture of spiegeleisen.

Mineral Resources of the World.—O. R. Kuhn, *Iron Ores of the World* (Blast-Furnace and Steel Plant, Jan. 1926, vol. 14, pp. 2–12). A broad survey of the important iron ore resources of the world. A very comprehensive table is given showing the types of ore found in the various mines, their analyses, and the treatment given before smelting.

Genesis of Ores.—R. Van Aubel, *The Part Played by Colloidal Solutions in the Formation of Mineral and Metalliferous Deposits* (Revue Générale des Sciences, Dec. 15, 1925, vol. 36, pp. 671–680).

II.—*PREPARATION OF ORES.*

Ore Concentration.—T. T. Read, *General Principles of the Beneficiation of Iron Ores* (Blast-Furnace and Steel Plant, Apr. 1926, vol. 14, pp. 172–179). Consideration of processes for the preparation of iron ores for subsequent metallurgical treatment presupposes a decision as to what that treatment is to be, and the author reviews the various ways in which iron is produced before discussing the actual beneficiation of the ores.

V. L. Eardley-Wilmot, *Molybdenum* (Canada, Department of Mines, Mines Branch, 1925, Report No. 592, pp. 205–239). The various methods for the concentration of molybdenum ores are described. The oil flotation process has proved to be more efficient than any other process. Various concentrating plants in operation in Canada and elsewhere are described, and particulars are included of their flow-sheets.

Ore Roasting and Sintering.—A. Weyel, *The Procedure and New Type of Plant for Roasting Spathic Iron Ore* (Report of Ore Committee of Verein deutscher Eisenhüttenleute, No. 7, 1924; Stahl und Eisen, Dec. 24, 1925, vol. 45, pp. 2117–2118). The large scale experimental roasting was carried out at the mines, and as the material lost 26 per cent. of its weight, this resulted in a considerable saving in freights. Temperatures of 600° to 800° C. are necessary for roasting spathic iron ore; under these conditions the roast appears blue-black in colour and is porous. Temperatures of 850° to 1000° C. cause sintering and partial fusion; sintering up to 900° C., which serves to bind the small pieces together, is wholly desirable, but above that temperature large masses frit together and cause trouble in the roaster and in the blast-furnace. The furnaces used in the experiments were cylindrical in form, 7 metres high by 3·9 metres internal diameter; they are provided with a plain door and a central iron chimney. They burn evenly, and show a slight economy in coke consumption with a small increase in output. By the use of induced draught, and by discharging and recharging twice daily, the output was increased to 58 tons per twenty-four hours per furnace, as compared with 40 tons when using natural draught only. It was found possible to use up to 20 per cent. of fine ore with the larger lumps; if larger quantities of fines require treatment, they can be simply and effectively briquetted by means of milk of lime. The evolved gases are easily absorbed in water, milk of lime, and solution of soda alternatively. Furnaces of square section give better results, and the most successful arrangement is in the form of a battery with two rows of furnaces, back to back. Besides being more convenient for charging and discharging, the heat loss is less.

Central Furnace to Sinter Dust (Blast-Furnace and Steel Plant, Apr. 1926, vol. 14, p. 196). The Central Furnace Company of Massillon, Ohio, are installing a Dwight-Lloyd sintering plant to deal with flue dust and scale from rolling-mills, to enable them to be smelted in the blast-furnace.

III.—*ORE MINING AND HANDLING.*

Ore Mining.—*Stripping the Overburden at Corby* (Iron and Coal Trades Review, Apr. 23, 1926, vol. 112, p. 691). Illustrated particulars are given of the Ruston revolving shovel used for stripping the overburden at the Corby mines of the Lloyds Ironstone Company.

R. E. Westwood, *Ironstone Mining in the Frodingham District* (Proceedings of the Lincolnshire Iron and Steel Institute, 1918–1920, vol. 1, pp. 152–158). The outstanding features in the mining of ironstone in the Frodingham district are briefly dealt with.

J. R. St. Clair, *A Unique Method of Iron Mining* (Blast-Furnace and Steel Plant, Dec. 1925, vol. 13, pp. 487–488). Photographs and a brief description are given of the scraper and raises used instead of locomotives and cars at the Miller Mine, Pitt Iron Mining Company, on the Mesabi Range.

F. W. O'Neil and H. Van Fleet, *Liquid Oxygen as an Explosive* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). The paper describes the present status and possibilities of liquid oxygen as an explosive for use in mines and quarries, based on the investigations of the Ingersoll Rand Co. and of the Air Reduction Co. Data are given on the cost of producing liquid oxygen with a 75-litre plant. Absorption ratios obtained in cartridges with various filling materials are tabulated, also the cost of unsoaked cartridges of varying sizes.

Ore Handling.—A. Schruff, *Modern German Practice in Ore-Handling Plant* (Iron and Coal Trades Review, Jan. 29, 1926, vol. 112, p. 192). An English abstract of an article, the original of which appeared in Stahl und Eisen, Sept. 3, 1925, vol. 25, pp. 1517–1521.

W. G. Hildebran, *Ore and Coal Bridges made Safe* (Blast-Furnace and Steel Plant, Aug. 1925, vol. 13, pp. 323–326, 335). A description of the Wellman-Seaver-Morgan safety stop equipment by which travelling bridges may be firmly wedged to withstand violent winds. The mechanism is automatic in operation, and is so arranged that wedges lock the wheels of the bridge to the rails at all times except when the operator steps on to his control platform.

Ropeways of Compañia Española de Minas del Rif (Iron and Coal Trades Review, Oct. 30, 1925, vol. 111, pp. 684–686). An illustrated description is given of the ore-handling plant of this company. The deposits are situated about 15 miles from Melilla. A railway runs up to a point about 1½ miles from the mines. Transport over the intervening distance between rail-head and the mines is accomplished by aerial ropeways, which work under the following conditions: Speed, 393 feet per minute; 150 loads per hour; net capacity of buckets, 20 cwts.

Prospecting for Ore.—S. F. Kelly, *Electrical Prospecting in Canada* (Transactions of the Canadian Institute of Mining and Metallurgy, 1924, vol. 27, pp. 278–306). A description is given of electric methods for the location of ore deposits, and the application of these methods to Canadian deposits is considered.

H. Lundberg, *Electrical and Electromagnetic Prospecting* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). The potential and electromagnetic methods of electrical prospecting for ore-bodies are explained.

Economics of the Mineral Industry.—*World Production and Consumption of Manganese Ore* (Mining Journal, Dec. 26, 1925, vol. 151, p. xi). The article quotes the Deutsche Bergwerks Zeitung, which expresses the opinion that the production of manganese ore in 1926 may exceed requirements owing to the great productivity of the Gold Coast. Productions for 1924 are shown and compared, and the productive capacities for 1926 of the four principal countries in the manganese ore industry are given as: Russia, 1,200,000 tons; Gold Coast, 450,000 tons; India, 600,000 tons; and Brazil, 250,000 tons, which totals to about 700,000 tons more than the average annual consumption of the world hitherto.

R. Navet, *Notes on the Purchase of Manganese Ore* (Revue Universelle des Mines, Nov. 15, 1925, vol. 8, pp. 227–240). Difficulties are frequently encountered by buyers of manganese ores in setting a correct value on any particular sample. In the case of rich ores, the influence of other elements, whether good or bad, may be very important. The author analyses the separate effects, due to a variation in the silica, iron, and manganese content, on the cost of the unit of manganese, and shows the alterations that should be made in the official offer. The calculations are worked out on general principles, and the use of the formulæ obtained is illustrated by concrete examples. Various useful tables are included.

REFRACTORY MATERIALS.

Preparation, Properties, and Tests of Refractories.—W. Hugill and W. J. Rees, *Silica Refractories for the Iron and Steel Industries* (Bulletin of the British Refractories Research Association, Apr. 1926, No. 12, pp. 170–186). Chemical composition, texture, mineralogical composition, thermal characteristics, mechanical properties, and storage of silica bricks are discussed. The changes in composition and structure during use are also dealt with.

W. Hugill and W. J. Rees, *The Effect of Repeated Burning on the Structure and Properties of Lime-Bonded Silica Bricks* (Transactions of the Ceramic Society, 1925–26, vol. 25, No. 1, pp. 82–93).

S. Sandlund, *The Addition of Chromic Oxide to Silica Bricks* (Jernkontorets Annaler, 1925, vol. 109, pp. 358–372). Describes the results of investigations made on silica bricks containing 95 to 90 per cent. silica and 0 to 4 per cent. chromic oxide.

E. H. Schulz, *The Testing of Refractory Materials used in the Metallurgical Industries of Germany* (Stahl und Eisen, 1925, vol. 45; Oct. 15, pp. 1733–1739; Oct. 22, 1777–1781). The author discusses the relative value and utility of the different tests to which refractory materials are usually subjected, and considers how far these represent the actual conditions of service. The tests usually prescribed are—complete analysis, the softening point as judged by Seger cones, heat resistance under load, porosity, specific weight, constancy of volume, structure, heat conductivity, spalling, and resistance to chemical action. The methods followed in making these tests are described, and a table of the heat conductivities of fireclay and silica bricks at 200° and 600° C. is given. Diagrams show the composition and properties of the majority of silica bricks in ordinary use to be as follows:—Silica, 94 to 95 per cent.; ferric oxide 1·25, lime 1·75, and alumina about 2·5 per cent.; softening temperature, 1720° C., corresponding to between cones 32 and 33; porosity, 22·5 per cent.; specific gravity, 2·37 to about 2·50; softening temperature under a load of 3·5 kilogrammes per square centimetre, 1550° to 1600° C.

Travers and de Goloubinoff, *Contribution to the Study of Silica Bricks—Dilatometric Analysis—Tests on the Raw Material* (Revue de Métallurgie, Mémoires, 1926, vol. 23; Jan., pp. 27–47; Feb., pp. 100–117). The paper commences with a historical review of the development of silica bricks, indicating the need that brought them into use. The dilatation of the various varieties of pure silica, and their practical preparation, are studied, in order that the quality of the bricks, which

is dependent on their constitution, might be determined by dilatometric methods. Reference is made to the optical method of O. K. Seaver for estimating tridymite, quartz, and cristobalite in the presence of each other, but objections are raised against its application. It is shown that the three crystalline varieties of silica possess instantaneous anomalies of dilatation, characteristic of each variety. It is reasonable, therefore, at the temperature of a transformation, to consider that the variety which undergoes the transformation is the one which dilates. The amount of the dilatation occurring at the temperature is proportional to the percentage of that particular constituent present.

F. H. Norton, *The Thermal Expansion of Refractories* (Journal of the American Ceramic Society, Dec. 1925, vol. 8, pp. 799–815). The thermal expansion or contraction of a number of typical refractories was measured up to 1700° C. in a neutral or slightly oxidising atmosphere. The following materials were tested: Silica brick, kaolin brick, fireclay brick, silicon carbide brick, zircon brick, zirconia brick, mullite brick, magnesite brick, chrome brick, spinel brick, lime brick, alumina brick, and insulating brick.

T. F. E. Rhead and R. E. Jefferson, *Notes on* (1) *Testing for Refractoriness and After Contraction;* (2) *A Few Experiences with Refractories in Vertical Retorts* (Transactions of the Ceramic Society, 1925–26, vol. 25, No. 1, pp. 6–38).

C. P. Williams and C. S. Graham, *Silica Brick Problems* (Proceedings of the Lincolnshire Iron and Steel Institute, 1918–1920, vol. 1, pp. 63–88). The paper gives a résumé of the work carried out by the authors on the testing of silica bricks.

F. H. Riddle and A. B. Peck, *An Eighteen Months High-Temperature Test on Refractory Test Specimens* (Journal of the American Ceramic Society, Jan. 1926, vol. 9, pp. 1–22).

M. L. Hartmann, O. B. Westmont, and S. F. Morgan, *The Determination of the Bulk and Pore Volumes of Refractory Materials* (Journal of the American Ceramic Society, May 1926, vol. 9, pp. 298–310). A new sand displacement method for the determination of the bulk volume and bulk specific gravity of refractory material is described. A gas porosimeter for the determination of pore volumes of materials is also described, together with calculations of the possible errors. The porosities, bulk specific gravities, and calculated true specific gravities of fifteen types of refractory bricks obtained by means of these two methods, and the usual water absorption method, are tabulated for comparison.

A. E. R. Westman, *The Mercury Balance—An Apparatus for Measuring the Bulk Volume of Brick* (Journal of the American Ceramic Society, May 1926, vol. 9, pp. 311–318). The mercury balance for measuring the bulk volume of bricks is described, and its method of operation is given in detail.

L. F. Sheerar, *The Effect of Atmospheric Conditions on the Load Test for Refractories* (Journal of the American Ceramic Society, May 1926,

vol. 9, pp. 279–289). Previous literature on the subject is reviewed and criticised. Iron pyrite was added to clays in amounts up to 5 per cent. Test-pieces were made by the stiff-mud and dry-press processes. After firing to cone 8 the test-pieces were subjected to load tests at 1350° C. under oxidising, neutral, and reducing conditions. Expansion and contraction values were plotted against time and temperature. Expansion and contraction increase with increase in pyrite content under reducing conditions.

P. Gilard, *Note on the Flaking of Refractory Bricks* (Revue Universelle des Mines, Jan. 15, 1926, vol. 9, pp. 81–89). The author shows that the flaking of the bricks is governed by three principal factors: thermal diffusion, expansion, and flexibility or maximum deformation under shear strain. There are other causes as well, such as the dilatation of quartz due to heat even in a uniformly heated brick. The remedy for minimising the flaking of the bricks lies in the method of manufacture, and the author points out some of the ways in which this may be effected, such as by increasing the grain-size of the lean material and reducing the amount of plastic matter, and by a preliminary burning of part of the clay.

A. J. Dale, *The Testing and Behaviour of Refractory Material under Stress at High Temperatures* (Bulletin of the British Refractories Research Association, Apr. 1926, No. 12, pp. 94–113). Previous work by the author and others on the behaviour of different types of refractory materials under stress at high temperatures is summarised. Typical load-test results provided by silica and firebrick materials differing widely in chemical, physical, and mineralogical constitution, are presented, and the industrial interpretations of these results are suggested

A. T. Green and A. J. Dale, *The Spalling of Refractory Materials* (Bulletin of the British Refractories Research Association, Apr. 1926, No. 12, pp. 127–169). A review of the work of previous investigators on the spalling and disintegration of refractories. A bibliography of the literature is appended.

A. T. Green, *The Thermal Properties of Refractory Materials, and a Consideration of the Factors Influencing them* (Bulletin of the British Refractories Research Association, Apr. 1926, No. 12, pp. 26–50). A survey of the work of different investigators on thermal properties of refractory materials, including specific heat, heat capacity, temperature diffusivity, thermal conductivity, and emissivity. A bibliography of the literature on the subject is appended.

A. J. Dale, *The Testing of Refractory Material for Resistance to Slag Corrosion and Erosion* (Bulletin of the British Refractories Research Association, Apr. 1926, No. 12, pp. 114–126). A review of the work of previous investigators.

A. Scott, *Corrosion of Steel Furnace Refractories* (Bulletin of the British Refractories Research Association, Apr. 1926, No. 12, pp. 60–71). The normal types of corrosion of refractory materials used in

steel furnaces are described. Two main types are met with: the first depends on the surface reactions which ensue between the corrosive agent, metal, slag or dust, and the materials of the refractory. The second is concerned with the penetration of the refractory by such agents and the physical disintegration which follows such penetration, the former effect invariably accompanying the latter. Other failures may be due to local overheating or to defects or weaknesses in the materials used.

J. T. Burt-Gerrans and R. S. Kerr, *The Electrical Conductivity of Magnesia Refractories at High Temperatures* (Transactions of the Royal Society of Canada, 1925, vol. 19, p. 27).

H. M. Henton, *Pyro- and Hydro-Treatment of Magnesite and Dolomite* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). The author describes an investigation which had for its object the separation of magnesia from the impure magnesite or the dolomite. The early laboratory experiments are described, with tables of tests, analyses, and other data. A plan of the experimental plant used is given and a suggested flow-sheet for a magnesia separation process is included.

J. F. Hyslop, *Fireclay Refractories* (Royal Technical College Metallurgical Club Journal, Glasgow, 1926, No. 5, pp. 31–32).

W. Groume-Grjimailo, *Qualities of Firebrick from a Metallurgical Standpoint* (Blast-Furnace and Steel Plant, Sept. 1925, vol. 13, p. 352). Notes on the qualities and use of firebricks for various metallurgical purposes.

J. H. Kruson and C. A. Smith, *The Manufacture and Physical Properties of Dry-Press Brick* (Journal of the American Ceramic Society, Dec. 1925, vol. 8, pp. 829–832). The process of manufacturing dry-press refractory brick is described, and the physical differences between dry-press and stiff-mud brick are enumerated.

J. S. McDowell, *The Mineral Constituents of Clay* (Journal of the American Ceramic Society, Jan. 1926, vol. 9, pp. 55–60). A review of the literature on the microscopic examination of clays.

J. S. McDowell, *Rational Analysis of Clay* (Journal of the American Ceramic Society, Jan. 1926, vol. 9, pp. 61–65). A review of the literature on the rational analysis of clays. The methods of determining the rational analysis are shown to be inaccurate.

R. S. Troop, *Some Dryer Considerations* (Bulletin of the British Refractories Research Association, Apr. 1926, No. 12, pp. 51–59). An outline is given of some of the problems involved in obtaining drying schedules, and of methods for the drying of refractories and of moulds and cores. Some of the factors which determine the efficiency of the plant and require consideration when installing new dryers are discussed. A short bibliography is included.

D. C. Lindsay and W. H. Wadleigh, *Some Observations on the Drying Properties of Clays* (Journal of the American Ceramic Society, Nov. 1925, vol. 8, pp. 677–693). The authors discuss the effects of shape,

temperature, vapour pressure, humidity, and the velocity of air currents as affecting the rate of drying.

J. Dautrebande, *Cement Base Refractory Materials* (Chaleur et Industrie, Feb. 1926, No. 70, pp. 75–76). Refractories with a clay base and carrying 30 to 40 per cent. of alumina have not proved satisfactory at very high temperatures. The alumina was increased to 50 and even 80 per cent., but the resulting materials were then very expensive. Cement agglomerates, made of a mixture of unground burnt cement and clinkers, were tried, and gave very good results, besides being much cheaper. The manufacture of bricks and concrete of this material is described.

United States Government Master Specification for Fireclay (United States Bureau of Standards, 1925, Circular No. 298).

Ceramics at the Bureau of Standards (Chemical and Metallurgical Engineering, Nov. 1925, vol. 32, pp. 867–869). A few notes on the work carried out on the development and production of refractories by the Bureau of Standards.

M. L. Freed, *A Study of Mullite Refractories formed by Calcining Cyanite; their Industrial Application* (Journal of the American Ceramic Society, May 1926, vol. 9, pp. 249–256). The paper is a progress report of an investigation dealing with refractory bodies made of cyanite, either raw or calcined. Specimens were subjected to standard and modified laboratory tests for high-grade refractories. Petrographic analyses indicate complete conversion to mullite in the test specimens, and the results of the tests indicate that the refractory is equal in quality to many so-called "super-refractories."

E. R. Thews, *Selecting Refractories for Use in Metallurgical Furnaces* (Iron Trade Review, 1926, vol. 78, Feb. 25, pp. 508–509, 513; Mar. 11, pp. 638–640). A discussion of the physical and chemical properties of refractories for use in metallurgical furnaces.

L. S. Longenecker, *Refractories for the Open-Hearth* (Iron Age, Dec. 24, 1925, vol. 116, pp. 1735–1738). The author describes the failure of magnesite brick in a large open-hearth furnace, and the subsequent tests undertaken to determine the cause. He puts forward tentative specifications for such brick, based on the results of the tests.

C. A. Smith, *Operating Conditions in the Open-Hearth as they Affect the Life of Refractories* (Journal of the American Ceramic Society, Dec. 1925, vol. 8, pp. 833–838). The author points out the more salient features of the deterioration of refractories under common operating conditions of the open-hearth furnace.

R. Hustin, *Fractional Fusion of Refractory Articles* (Chimie et Industrie, Nov. 1925, vol. 14, pp. 691–692). The author was asked to study the linings of certain reheating furnaces which were wearing out in only about eight days. A special variety of bricks was introduced, and the service was increased to four weeks. During the first week it was noticed, however, that partial fusion was taking place, but that it stopped automatically after that period. Analysis of the

fused face and sound back of a brick showed that the SiO_2 content was lowered from 78·8 to 56·3 per cent. by the fusion, the Al_2O_3 was raised from 18·28 to 31·53 per cent., and the other bases were also increased in proportion. As the bricks were only in contact with coke, it was assumed that the latter had introduced fluxes little by little, and these had gradually slagged off the "excess" SiO_2 at comparatively low temperatures; when this process had finished the slagging action stopped, and the increased Al_2O_3 content formed a protective layer on the bricks, which behaved in a more satisfactory way for a further three weeks. It was calculated that the slagging action removed 51 per cent. of the brick.

H. A. Schwartz, *Principal Refractory Problems of the Malleable Cast-Iron Foundry* (Journal of the American Ceramic Society, Nov. 1925, vol. 8, pp. 708–711). The author describes briefly the necessary conditions under which firebricks are used in air-furnace melting, and outlines some of the elementary relations between fuel economy and refractory economy.

R. Moldenke, *Refractory Requirements in the Grey Iron Foundry* (Journal of the American Ceramic Society, Nov. 1925, vol. 8, pp. 712–719). The author calls attention to the lack of information on foundry refractories on the part of both foundrymen and manufacturers. The applications of refractories in foundry practice are enumerated.

J. T. Mackenzie, *The Effect of Variations in Cupola Practice on the Life of the Refractory Blocks* (Journal of the American Ceramic Society, Nov. 1925, vol. 8, pp. 720–734). The paper discusses the chemical, mechanical, and physical influences acting on cupola linings, and their combined effects. A brief description is given of common practice in the lining, preparation, and charging of cupolas, and the effect of daubing practice, the character of the fuel, metal, flux, and blast, are discussed. The principal point of the paper is the injurious effect of oxidation resulting from thin or rusty scrap and from too high velocity of blast.

F. H. Norton, *The Design of Arches for Kilns and Furnaces* (Journal of the American Ceramic Society, Mar. 1926, vol. 9, pp. 144–150). The design of arches is considered from the viewpoint of minimising the static and temperature stresses. The catenary shape of arch is most satisfactory, as it allows the use of a high arch with good stability.

A. H. Middleton, *Refractory Materials in Carbonising Practice* (Paper read before the North of England Gas Managers' Association, Oct. 16, 1925: Gas Journal, Oct. 21, 1925, vol. 172, pp. 163–166). The greater refractoriness and greater heat conductivity of silica more than compensates for its higher original cost in the building of carbonising plant. Silica has no wide range of softening such as have semi-silica and fireclay, and maintains its rigidity right up to the point of collapse, thus allowing the plant to be run at a temperature nearly 300° C. higher than is safe with other refractories. The use of silica allows of a much greater throughput due to its better conductivity and the higher temperatures its use makes possible. The author

bears out his opinions by reference to the practical working of a sixty-oven battery at the Fell Coke Works, Consett.

S. S. Cole, *Properties of Silica Brick from Coke-Oven Walls* (Journal of the American Ceramic Society, Apr. 1926, vol. 9, pp. 197–202). The author has investigated the change occurring in silica bricks after long service. Bricks from the Chicago and Birmingham districts were examined. Chemical analyses, and specific gravity, porosity, fusion values, and petrographic examinations were carried out. It is concluded that silica bricks made from different quartzites have like properties after long service. Very little change in chemical composition occurred, and very slight change in porosity resulted. The long service brought about a conversion of the quartz to cristobalite and tridymite. On the flue face of the brick chiefly tridymite was present, while on the coke face cristobalite was predominant. The silica bricks were in good condition after twelve years of continuous service at operating temperatures probably as high as 2500° to 2600° F. The only vitrification which had occurred was a glazed surface on the flue face.

A. E. J. Vickers and A. T. Green, *The Trend of Design in Modern Coke-Oven Construction, and its Bearing upon Refractory Materials* (Bulletin of the British Refractories Research Association, Apr. 1926, No. 12, pp. 73–93). The supply, utilisation, and transmission of heat in the oven, thermal conductivity of the wall and charge, transfer of heat from flame to oven wall, and the velocity of the gases in the heating flues, are discussed, and the systems of heating the different types of ovens are shown diagrammatically. The properties of coke-oven bricks are also discussed. The various advantages of silica appear to lie in its constant physical properties. The silica material stands up better under load, it is more resistant to corrosion, and enables ovens to be operated at quicker rates than does fireclay.

P. B. Robinson, *The Use of Silica Refractories* (Journal of the Society of Chemical Industry, Jan. 29, 1926, vol. 45, pp. 29–33T). A discussion of the properties of silica, with special reference to the use of silica bricks in the construction of coke-ovens.

G. E. Junius, *Refractory Materials used in the Manufacture of Coke* (Brennstoff-Chemie, May 1, 1925, vol. 6, pp. 139–143). An account is given of the development of the use of refractories for building coke-ovens, with a description and a comparison of the German quartzite called "Findling" and with the American quartzite found in Pennsylvania.

F. C. Bishop, *Some Experiences with Salty Coal and Brick Corrosion* (Paper read before the Coke-Oven Managers' Association, Feb. 18, 1926).

M. C. Booze, *Refractories for Blast-Furnaces and Coke-Ovens* (Blast-Furnace and Steel Plant, Feb. 1926, vol. 14, pp. 86–88). A review of the general characteristics of refractories used in blast-furnaces and coke-ovens, the changes that might be made in them, and the effects that these alterations might have on their service.

H. G. Fisk, *A Practical Gas-Fired Test Furnace for Plant Use* (Journal of the American Ceramic Society, Mar. 1926, vol. 9, pp. 151–

153). A brief description is given of a gas-fired furnace for carrying out fusion, firing, spalling, slagging, and load tests of firebricks.

F. H. Norton, *A Laboratory Kiln for Obtaining High Temperatures* (Journal of the American Ceramic Society, Dec. 1925, vol. 8, pp. 826–832). A small gas-fired laboratory kiln is described capable of firing or melting refractory materials up to 1850° C. It is pointed out that the flame temperatures reached approach the theoretical values computed from the heat of combustion and the specific heat of the products of combustion.

J. Mitchell and W. B. Mitchell, *Laboratory Furnace for High Temperatures* (Transactions of the Ceramic Society, 1925–26, vol. 25, No. 1, pp. 39–50). The authors describe an electric furnace of the metallic resistor type, designed specially for the testing of refractories.

Heat-Insulating Material.—A. T. Green, *The Properties of Heat-Insulating Material for High-Temperature Metallurgical Plant* (Bulletin of the British Refractories Research Association, Apr. 1926, No. 12, pp. 13–25). The essential properties of high-temperature insulating materials are discussed. Although a great number of insulating materials and compositions are on the market, the demands of high-temperature insulation can only be met by a few, including slag wool and diatomaceous earth products. The selection of insulating material cannot be based on insulating efficiency alone. A knowledge of the circumstances of its future use, particularly regarding the face temperature to which it will be subjected, is essential. The following data will serve in the selection of material: (*a*) The coefficient of thermal conductivity at temperatures between 300° and 800° C.; (*b*) percentage porosity, together with a description of the nature of pore spaces; (*c*) refractoriness, together with the temperature at which the material disintegrates; (*d*) crushing strength. One of the most important limiting factors in the use of insulating material is the structural efficiency of the inner wall of the refractory material.

High-Temperature Insulation (Engineering, Nov. 13, 1925, vol. 120, p. 605). A brief description of "Sil-o-cel," made by the Celite Products Company. The material is very porous, due to the presence within its mass of a large number of small air cells, which materially increase its heat-insulating properties. It is light, and its crushing strength in brick form is 400 lbs. per square inch; it is not, however, intended to displace refractory materials, but only to be used as an insulator.

Steel Ladle Linings.—A. Schmitz, *The Torkret Process in Iron and Steel Works* (Stahl und Eisen, Jan. 7, 1926, vol. 46, pp. 13–16). The Torkret process offers a new method for the lining of furnaces, cupolas, or ladles, without the necessity of moulding or ramming the material; the apparatus used being known as the cement gun, of which an illustrated description is given. The refractory material, in pulverised form, is fed dry into a chamber, whence it is blown by compressed air

through a hose. A supply of water is brought through a separate small hose, and led into the nozzle of the larger hose conveying the stream of powdered refractory. The mass becomes intimately mixed and is sprayed on to the wall of the vessel it is desired to coat. The air pressure necessary for successful working is from 2½ to 3½ atmospheres, and the water pressure must be slightly higher than the air pressure in order to penetrate the dry mass. The stream of dry powder can be conveyed through the hose over distances up to 250 metres and to a height of 50 metres. The material is ground to a size of 0 to 3 millimetres; if it is used in too fine a state the water does not mix regularly and the mass may be too wet and then too dry. Brick-lined ladles can be coated after cleaning and washing out, the usual practice being to turn them on their side and fill out the worn places first by "torcreting," and then spray the surface evenly to a thickness of about 1¼ inches. A very considerable saving results in the life of ladle linings.

FUEL.

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I.—*CALORIFIC VALUE.*

Fuel Value of Coal.—R. H. Sweetser, *Evaluating Various Grades of Coal* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926: Iron Age, Mar. 11, 1926, vol. 117, pp. 685). The author emphasises the need for an intelligent classification of the grades of bituminous coal, similar to that in use for iron ores.

G. Weyman, *Examination and Evaluation of Coals for Carbonising Purposes* (Gas Journal, 1926, vol. 173; Mar. 10, pp. 601–603; Mar. 17, pp. 677–679; Mar. 24, pp. 746–747). The various methods of examining coals are considered, and the conclusion is drawn that the only way to obtain information of use in evaluating the coals is by means of a process which imitates more or less closely works practice, and works on a reasonably large sample. A description is given of the furnace specially designed by Dr. E. W. Smith for carrying out tests on $\frac{1}{1000}$-ton quantities, and of the method of operation. The evaluation of the test results obtained is described.

C. E. Augustine, J. Neil, and W. M. Myler, jun., *Value of Bituminous Coal and Coke for Generating Steam in a Low-Pressure Cast-Iron Boiler* (United States Bureau of Mines, 1925, Technical Paper No. 367). This report is the second of a series dealing with the combustion, at low rates, of various fuels in boilers and furnaces. The first report is contained in Technical Paper No. 303.

Coal Ash.—A. C. Fieldner and W. A. Selvig, *Relation of Ash Composition to the Uses of Coal* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). Although the usual proximate analysis of coal gives the amount of ash, it gives no information on the nature and composition of the ash, nor of the mineral composition from which it is produced. These constituents may be roughly classed as either inherent or extraneous impurities, depending on whether they are mixed intimately with the coal substance, and derived

from the original coal-forming material, or whether they are present in the coal-bed as partings, bands, or nodules of pyrite, shale, and slate. Considerable sulphur may occur in other forms than that combined with iron as pyrite or marcasite. The reactions of the sulphur compounds of coal are of special interest in the production of metallurgical coke. Iron may occur in at least five different forms, but the dominating variety is pyrite. The softening or fusing temperature of coal ash is of particular interest, because of clinker and slag trouble often experienced. If the ash-forming minerals consist principally of siliceous and argillaceous material, the ash is not readily fusible, but the contrary is the case when they contain considerable amounts of calcite, gypsum, or pyrite. Impurities, such as slate, sandstone, or shale, tend to raise the fusibility of the ash. Powdered coal for iron and steel metallurgy should be low in sulphur. For open-hearth furnaces the ash should be limited to 6 per cent. and the sulphur to 1 per cent. Coal with readily fusible ash is not desirable for smithing use, and high-sulphur coals are objectionable because of the occurrence of red-shortness in the iron under treatment.

P. Grandjean and A. Rothen, *The Fusion Point of Ashes, and its Relation to their Analytical Composition* (Chaleur et Industrie, 1925, vol. 6, Nov., pp. 530–535; Dec., 582–591). The ordinary method of determining the fusion point of ashes is liable to error; chemical changes are taking place within the ash, and the course of these may be caused to vary by altering the nature of the gases of the furnace in which the determination is being made. By standardising the conditions the accuracy of the Seger cone method may be considerably increased, but the test at best gives only empirical results. The authors seek to base a method on the chemical analysis of the material; the problem apparently resolves itself into the study of the quaternary system silica-alumina-lime-ferrous oxide. It is important that the iron should be maintained in the ferrous condition during the test.

J. Lilot, *The Influence of Ash Contents on the Value of Blast-Furnace Coke* (Revue Universelle des Mines, Apr. 1, 1926, vol. 10, pp. 39–43). By means of calculations, the author demonstrates that the effect of the ash in the coke is to increase the amount of slag formed, and also the amount of heat absorbed by this slag. Increase in the ash contents lowers the useful calorific power of the coke and increases the amount of lime necessary. Further, manganese is dissolved by the slag formed by the ash, and the amount of carbon gasified in the blast-furnace is reduced as the ash increases, and the amount of CO produced diminishes in the same proportion.

R. Lessing, *Coal Ash and Clean Coal* (Journal of the Royal Society of Arts, 1926, vol. 74; Jan. 15, pp. 182–197; Jan. 22, pp. 205–218; Jan. 29, pp. 224–241). In the first lecture mineral matter in its relation to the formation and constitution of coal is discussed, and some of the methods employed in the study of its distribution throughout the coal mass are described. In the second lecture the bearing of mineral matter

upon the production of coal is examined. The third lecture deals with the influence of the mineral constituents on the utilisation of the coal.

Pulverised Coal.—W. R. Chapman, *Pulverised Fuel for Boilers and Furnaces* (Fuel, 1925, vol. 4, Oct., pp. 420–424; Nov., pp. 486–492). The author continues his account of practice in the use of pulverised fuel, dealing with the efficiency of the method of powdered coal-firing as compared with other methods. For furnace heating of any sort it is fully 20 to 30 per cent. cheaper than hand or stoker firing, is more flexible, and is smokeless. For open-hearth melting it is not so practicable as the use of gas.

D. Brownlie, *The Most Recent Progress in Connection with Pulverised Fuel* (Chaleur et Industrie, Nov. 1925, vol. 6, pp. 499–506). A description of modern plant and procedure; the article is subdivided under the following headings: Drying of coal, pulverisation, construction of the combustion chamber, the large dimensions of the boilers, heating the air, superheaters using radiated heat, increasing the thermal efficiency, fuels from "waste," the application of pulverised fuel to the coal industry, and pulverised fuel and low-temperature carbonisation.

Pulverised Fuel Practice in Relation to Fuel Economy and Efficiency (Fuel Economist, 1925, vol. 1, Oct., pp. 21–24; Nov., pp. 81–88).

P. Rosin, *The Thermodynamic and Economic Factors in Coal-Dust Firing (Dried German Brown-Coal)* (Braunkohle, 1925, vol. 24, pp. 241–259, 269–273). A general review of all the conditions for the efficient utilisation of powdered brown-coal for industrial heating.

A. J. T. Taylor, *Pulverised Fuel in Some Commercial Aspects* (Transactions of the Institution of Engineers and Shipbuilders in Scotland, 1924–25, vol. 68, pp. 11–72).

E. Kilburn Scott, *Pulverised Fuel Firing* (Paper read before the Institute of Marine Engineers: Iron and Coal Trades Review, Dec. 11, 1925, vol. 111, p. 962). The combustion, preparation, and uses of pulverised fuel are discussed.

G. P. Dennis, *Pulverised Coal* (Transactions of the Liverpool Engineering Society, 1924, vol. 45, pp. 168–201). An illustrated account of different systems for the preparation of pulverised fuel and its use under boilers.

R. Jackson, *Pulverised Coal* (Transactions of the Manchester Association of Engineers, Session 1924–25, pp. 201–238). The preparation and use of pulverised fuel under boilers is discussed.

Pulverised Coal (Mining Journal, Jan. 16, 1926, vol. 152, pp. 50–51). A brief note on the use of pulverised coal under boilers, and a description of the "Atritor" machine. This is claimed to have many advantages over the "central" system, the machine being relatively small and self-contained, and requiring a smaller staff to attend to it than does the ordinary coal-crushing plant.

R. S. Riley and O. Craig, *The Development of a Unit Pulveriser* (Mechanical Engineering, mid-Nov. 1925, vol. 47, pp. 1047–1052).

Describes the development of the "Atritor" machine for preparing coal to be burnt in powdered form, from its first to its present state of evolution. Tests carried out and the results obtained are described and discussed. The present machine needs little maintenance, can pulverise wet coals, and is reliable, as foreign matter is separated from the coal without damage to internal parts. During capacity tests, Eastern bituminous coal with 3 to 5 per cent. moisture was pulverised at the rate of 6750 lbs. per hour for an expenditure of 6·7 kilowatt-hours per ton. The fineness of the product was 81 per cent. through a 200-mesh screen with 2·6 per cent. remaining on a 50-mesh screen.

A. G. Christie, *Boiler Furnaces for Pulverised Coal* (Mechanical Engineering, 1925, vol. 47, pp. 632–635).

W. J. Wohlenberg and D. G. Morrow, *Radiation in the Pulverised Fuel Furnace* (Mechanical Engineering, 1925, vol. 47, pp. 627–632).

E. G. Ritchie, *Radiant Heat Absorption in Pulverised Coal Furnaces* (Electrical Times, 1925, vol. 68, Aug. 27, pp. 221–224; Sept. 3, p. 249).

Gyro Gasification (Iron and Coal Trades Review, Jan. 8, 1926, vol. 112, pp. 58–59). An illustrated description is given of the Gyro system of pulverised fuel firing, which consists of a pulveriser and a gasifier; the latter is circular or oval in section and takes the place of the usual furnace boiler. The coal in the pulveriser is reduced to size by rapid impact against beaters mounted on a vertical shaft, and is drawn by draught at high velocity to the gasifier. Mixing, ignition, gasification, and complete combustion occur in progressive stages of completeness. The gasifier is lined with a high-grade aluminous brick, known as "Leolite," capable of withstanding a temperature of 1850° C.

The "Gyro Gasification" of Coal (Electrical Review, Apr. 16, 1926, vol. 98, pp. 609–611). A description of the use of powdered coal on the Lindley-Duffield system in the boilers of the Dover Corporation Electricity Works.

Powdered Coal Plant at Dover (Engineer, Mar. 19, 1926, vol. 141, 319–320). Another description of the pulverised fuel plant of the Dover Corporation Electricity Works.

E. C. Kreutzberg, *Pulverised Coal at the Furnace* (Foundry, Jan. 1, 1926, vol. 54, pp. 7–8; Iron Trade Review, Jan. 28, 1926, vol. 78, pp. 262–263). Illustrated particulars are given of a new type of coal pulveriser which is attached to the furnace, thus doing away with storage facilities. The pulveriser can be used with malleable iron furnaces.

W. Hathaway, *Malleable Furnace Fired with Pulverised Fuel* (Foundry, Oct. 15, 1926, vol. 53, pp. 824–828). A general account of the methods employed in using pulverised fuel in melting and annealing furnaces for the production of malleable cast iron. Comparative data are given in tables showing the financial advantages of pulverised coal-firing over hand-firing.

Waste Fuel Recovery.—*The Dry Magnetic Process for Recovering Coke from Pan Ash* (Gas World, Jan. 23, 1926, vol. 84, pp. 86–88).

Illustrated particulars are given of this process for the separation of the incombustible portions of furnace residues.

C. H. S. Tupholme, *Recovering Fuel from Ash and Clinker* (Electrical Review, Nov. 20, 1925, vol. 97, pp. 804–806). An account of some of the machines used for salvaging unburnt fuel from the ash and clinker from furnaces. The froth flotation principle is outlined, and brief descriptions of the Blackett washer and Columbus separator, among others, are given. Magnetic separation is also described.

B. I. Rolling, *Machines Used in Magnetic Separation* (Paper read before the Institution of Chemical Engineers, Dec. 9, 1925). Reference is made to the process used by Krupps for the separation of slags containing iron from coke and other fuel residues.

Industrial Heating.—T. C. Mitchell, *Coal, and Some of its Industrial Uses* (Royal Technical College Metallurgical Club Journal, Glasgow, 1925, No. 4, pp. 34–36).

Classification of Coal.—F. Bössner, *Coal and Coke Standards* (Gas und Wasserfach, 1925, vol. 68, pp. 507–508). The author points out and discusses the irregularities in Continental usage with regard to the classification of coal and coke according to size.

II.—*COAL.*

United Kingdom.—W. S. Boulton, *Evidence for an Easterly Extension of the Warwickshire Coalfield* (Transactions of the Institution of Mining Engineers, 1925, vol. 70, pp. 69–78).

G. V. Wilson, *The Concealed Coalfield of Yorkshire and Nottinghamshire* (Memoirs of the Geological Survey of England and Wales, 1926). The concealed part of the Yorkshire and Nottinghamshire coalfield has been proved by the borings and shafts described in the memoir to cover about 1200 square miles.

The Lancashire Coalfield, Smith Seam (Department of Scientific and Industrial Research : Fuel Research Board, Physical and Chemical Survey of National Coal Resources, No. 5). A description and geological sketch map are given of the Lancashire coalfield, together with diagrammatic cross-section figures of the Smith, Rushby Park, and Dandy seams.

J. E. Richey, G. V. Wilson, and E. M. Anderson, *The Economic Geology of the Ayrshire Coalfields. Area* 1 (Geological Survey of Scotland, Edinburgh, 1925). The first of a series of short memoirs devoted to a description of the Ayrshire coalfields. A summary of the geology of the district (Area 1), which includes Lochwinnoch, Kilbirnie, Beith, Dalry, Saltcoats, Stevenston, Kilwinning, and Kilmaurs, is followed by a detailed account of the different formations, arranged in geological

order. The second memoir of the series is by E. M. Anderson, and includes the greater part of North Ayrshire. It deals mostly with the coal measures of the Kilmarnock basin, which extend from Saltcoats to near Darvel.

R. Kidston, *Fossil Plants of the Carboniferous Rocks of Great Britain* (Memoirs of the Geological Survey of Great Britain, Palæontology, vol. 2, Part VI., pp. 523–670. London, 1925. H.M. Stationery Office).

Africa.—W. J. Wybergh, *The Coal Resources of the Union of South Africa* (Geological Survey of the Union of South Africa. Memoir No. 19. In 2 vols.). Volume 1 of this memoir deals with the coalfields of Witbank Springs, Heidelberg, and the Orange Free State, and Volume 2 with the inland coalfields of Natal, describing in each case the general character of the coal measures, the coal seams, and giving an estimate of the coal reserves. The coal measures of the Klip River coalfield consist of shales, sandstones, grits, and coal seams, with occasional thin beds of ironstone. Most of the coal marketed is an excellent steam coal. The Vryheid coalfield consists of a number of coal-bearing areas. The coal measures consist of clay shales, carbonaceous shales, and workable coal seams interstratified with sandstones. A good deal of the coal is of high coking quality. There are three producing collieries in the Utrecht coalfield, two of which are of considerable importance. The coal measures consist of sandstone and shales, and the latter include some beds of oil shale. The coal varies from semi-bituminous to bituminous, but the percentage of ash is very low.

J. Kersten, *Coals in the Union of South Africa* (Revue Universelle des Mines, Jan. 1, 1926, vol. 9, pp. 6–26). A review of the distribution, mode of occurrence, and methods of mining of coal in the Union.

R. C. Wilson, *Brown-Coal in Nigeria* (Geological Survey of Nigeria, 1925. Occasional Paper, No. 1). The main portion of this paper is devoted to a general account of the developments that have taken place in the utilisation of lignite or brown-coal for fuel purposes. Prior to the war, practically the only uses of lignite were direct combustion for domestic uses in localities where coal was not available, or briquetting where its low cost of production made its use in industrial works cheaper than coal. It was, however, during the war that the use of lignite was greatly extended. In Germany it was used as a fuel in the industrial establishments, including the nitrate factories. It was also used as a source of distillates, including paraffins and lighter burning oils. Since the war much development work has been carried on in Germany, America, Canada, and Australia. Particulars are given, compiled from various sources, of the results of tests on the carbonisation of lignite. Analyses are also included of Nigerian lignites.

Albania.—E. Nowack, *The Coal Occurrences of Albania* (Montanistische Rundschau, Feb. 1, 1926, vol. 18, pp. 69–84). A full description, with maps and sections, is given of the Albanian coal deposits. They

consist mainly of late Tertiary coal formations, and have little economic value except for local purposes.

Australia.—*Coal Resources of New South Wales* (New South Wales Geological Survey, 1925, Bulletin No. 6). Particulars are given of recent developments and new discoveries in the coalfields of the State.

Brazil.—F. Weinmann, *The Coal-Mining Industry of Southern Brazil* (Glückauf, Aug. 22, 1925, vol. 61, pp. 1050–1057). The coal formations and methods of mining the coal are described.

Canada.—E. Stansfield, R. T. Hollies, and W. P. Campbell, *Analyses of Alberta Coals* (Scientific and Industrial Council of Alberta, 1925, Report No. 14, pp. 9–63). The report contains numerous proximate analyses of Alberta coals from sixty-two districts.

China.—C. Yu Wang, *The Coal-Mining Industry in China* (Colliery Engineering, Nov. 1925, vol. 2, pp. 489–491). A brief survey is given of the coal deposits and progress in mining in China.

Germany.—E. Jüngst, *Ground Ownership in the Rhenish-Westphalian District* (Glückauf, Jan. 2, 1926, vol. 62, pp. 14–22). A list of the mining properties in the Ruhr district, with names of owners and outputs of the various undertakings, is given. A large-scale coloured map accompanies the article, on which the area of every property and position of all the mine shafts are marked.

M. Dolch, *The Characteristics of certain Brown-Coal Deposits* (Braunkohle, 1925, vol. 24, pp. 393–398, 439–443). The author discusses the geological and physical characteristics of brown-coal from the Piberstein-Lankowitz deposits. Its behaviour on coking and the properties of the by-products are also dealt with.

India.—A. Jowett, *On the Geological Structure of the Karanpura Coalfields, Bihar and Orissa* (Memoirs of the Geological Survey of India, 1925, vol. 52, Part I., pp. 144).

New Zealand.—T. C. Hewitt, *Coal Deposits and Mining in New Zealand* (Colliery Engineer, Jan. 1926, vol. 3, pp. 14–25). A survey is given of the geology of the coalfields and of practical mining conditions in New Zealand.

Spitsbergen.—C. Klees, *The Development and Economic Importance of the Coal-Beds of Spitsbergen* (Glückauf, Oct. 3, 1925, vol. 61, pp. 1251–1257). A short description of the geology of Spitsbergen, with maps, is first given, and the author then proceeds to describe the coal-mines and the conditions under which they are worked. In 1924 the output rose to 460,000 tons, and within the next ten years, if the present plans of

development are carried out, the production may be expected to reach one million tons annually. As regards the climate, the temperature in the island ranges from 12° C. in summer to — 40° C. in winter, the mean temperature throughout the year being — 9° C. The ground is frozen to a depth of about 1300 feet. Five mines are in operation, of which two are owned by Norwegians and the other three by Swedish, Dutch, and Anglo-Russian interests respectively. The total reserves are estimated at about 5000 million tons of Tertiary coal. The coal is bituminous, fairly hard, shiny black, and lumpy, and analysis shows it consists of : Moisture 1·48, ash 7·68, volatile 32·77, carbon 58·07 per cent., with a calorific value of about 7500 cals. The mines are all worked by adits opening from the cliffs of the shore, and within the workings the temperature never exceeds — 2° C., falling in winter to —4° C. In consequence the men work briskly, and the output per man is higher than anywhere else in the world, a hewer's daily amount being 4 to 5 tons, while the output per head of the entire staff is 3·2 to 3·4 tons per day of 8 hours. The wages are, however, about double as much as those prevailing in Europe, and Spitsbergen coal cannot yet compete in European markets.

United States.—J. D. Sears, *Geology and Coal Resources of the Gallup-Zuni Basin, New Mexico* (United States Geological Survey, 1925, Bulletin 767). The report describes the geology and resources of the basin in a general way, and the coal-beds of the Gallup district and the Zuni Indian Reservation in detail.

Analyses of Virginia Coals (United States Bureau of Mines, 1926, Technical Paper 365). This paper is one of a series containing analyses of the coals of the different States of the United States. The present paper contains analyses of mine samples of Virginia coals, and includes a brief description of the geological structure of the coal-basins and typical mining conditions in the different districts.

Analyses of Alabama Coals (United States Bureau of Mines, 1925, Technical Paper No. 347). Analyses of numerous samples of coals from different localities of Alabama are given. A brief description of the geological structure of the coal-basins, as well as particulars of typical mining conditions in the State, are also included.

Constitution and Chemistry of Coal.—V. H. Legg and R. V. Wheeler, *The Composition of Coal* (Mines Department, Safety in Mines Research Board, 1926, Paper No. 17). A characteristic ingredient of many bituminous coals is cuticularised tissue, the outer protective covering of leaves and stems common to all living plants. The chemical composition and the properties of the cuticles differ widely from those of the ulmic ground-mass of the coal in which they lie embedded. In the belief that the existence of cuticles in a coal imparts to it properties which it would not otherwise possess, and therefore distinguishes it from a coal of similar ultimate chemical composition from which

cuticles are absent, a study is being made of their properties. This study is being directed particularly to the problems of spontaneous combustion of coal and the inflammability of coal dust. As an aid to this investigation, the chemical composition of modern plant cuticles has been determined. A further step is rendered possible by the existence in Russia of an unique deposit of coal, the so-called "paper-coal," composed almost entirely of cuticles. A description of this coal is given.

D. White, *Progressive Regional Carbonisation of Coal* (Transactions of the American Institute of Mining and Metallurgical Engineers, 1924–25, vol. 71, pp. 253–281). The author discusses the progressive alteration (metamorphism) or carbonisation of coal from rank to rank, under geological conditions, which is to be observed within the same formation.

R. Thiessen, *The Microstructure of Coal* (Journal of the Royal Society of Arts, Apr. 23, 1926, vol. 74, pp. 535–557). The paper describes the life-history of coal, how it came to exist, what plants contributed, how and where they grew, and after death and decay, what remained of them, and how the residue finally turned into coal.

H. Tropsch, *The Chemical Constitution of Coal in Relation to its Utilisation* (Zeitschrift des Vereines Deutscher Ingenieure, July 4, 1925, vol. 69, pp. 899–903). A discussion of the constituents of coal upon which the coking properties of the coal depend, and of other compounds affecting the utilisation of coal for various purposes.

S. W. Parr and F. B. Hobart, *Coal and Oxygen* (Transactions of the American Institute of Mining and Metallurgical Engineers, 1924–25, vol. 71, pp. 216–226). The authors have carried out tests to determine the rate of absorption of oxygen by coal, and the ignition temperature of coals in a current of oxygen. The avidity of the cellulosic residue of coal for oxygen was also studied.

W. A. Bone and R. Quarendon, *Researches on the Chemistry of Coal. Part IV. The Oxidation of the Residue from the Benzene-Pressure-Extraction Process* (Proceedings of the Royal Society, Mar. 1, 1926, (A), vol. 110, pp. 537–542).

J.-W. Meuser Bourgognion, *The Sulphur Contained in Coal and Coke* (Gas (The Hague), Apr. 1, 1925, vol. 45, pp. 97–107). A study of the equilibrium between the sulphur-carbon complex and carbon at high temperatures, according to the Phase Rule. It is shown that the sulphur may exist as absorbed free sulphur, or as a solid solution of sulphur in carbon; or the sulphur may be held on the surface of the carbon in a form which is indistinguishable from a solid solution. If the coke is kept at a red heat for a long time the free sulphur passes into solid solution. Coke obtained by the ordinary methods of manufacture contains the sulphur, before cooling, as free sulphur and in solid solution and as FeS. On cooling, this latter oxidises in the presence of even very little air, giving free sulphur, but quenching causes the oxidation to be incomplete. Passage of hydrogen, or gases rich in

this element, through the incandescent coke liberates the sulphur as H_2S; of all the sulphur compounds in coke, FeS has the highest decomposition constant. The above explains the difficulties attending the desulphurisation of coke.

W. J. Huff, *The Origin of Carbon Disulphide in the Carbonisation of Coal* (Industrial and Engineering Chemistry, Apr. 1926, vol. 18, pp. 357–361). Coal was carbonised without producing detectable quantities of carbon disulphide when it was heated slowly and allowed to gasify freely, but when it was heated so rapidly that a dense, coherent coke was formed from a high volatile coal, carbon disulphide was found in the products of gasification, although the quantity of coal used was small, and the tarry and gaseous products were in contact with the carbon in a small space and for a short time. A possible explanation is that, when heated suddenly, the sulphur and carbon may react chemically in regions where there is a deficiency of carbon and hydrogen. Slow heating would allow these local deficiencies to be corrected by diffusion, and so prevent the formation of carbon disulphide.

Nomenclature of Coal.—E. R. Franz, *Bitumen and Bituminous Coal. Definitions* (Fuel, Nov. 1925, vol. 4, pp. 494–497). A compilation is given of definitions of the words "bitumen" and "bituminous coal," and a number of authorities, ancient and modern, are quoted, describing the characteristics of various substances which have been termed bituminous.

C. A. Seyler, *The Nomenclature of the Banded Constituents of Coal* (Journal of the Royal Society of Arts, May 7, 1926, vol. 74, pp. 609–610). The author defines the relation between the terms vitrain, clarain, durain, and fusain, introduced by Dr. Stopes, and anthraxylon and attritus, devised by Dr. Thiessen.

Utilisation of Peat.—S. Oden, *Peat and Peat Problems in Sweden* (Fuel, Dec. 1925, vol. 4, pp. 505–527). An account is presented of the present state of scientific research with regard to peat and peat problems; the formation and constitution of different kinds of peat, their composition and treatment, are fully dealt with, with a view to their utilisation as fuel.

G. L. Stadnikoff, P. Mehl, and W. Putzilo, *The Artificial Drying of Peat* (Brennstoff Chemie, Nov. 1925, vol. 6, pp. 333).

III.—*COKE.*

Solid Smokeless Fuels.—*Solid Smokeless Fuel* (Engineering, Nov. 27, 1925, vol. 120, pp. 686–687). A report, with abstracts of papers, of a joint meeting held in Sheffield on Nov. 20, 1925, by the Chemical Engineering Group and the Yorkshire Section of the Society of Chemical

Industry, the Institute of Chemical Engineers, the Institute of Gas Engineers, and the Midland Institute of Mining Engineers. The following papers were presented: *Principles and Practice of Coke Manufacture, with Particular Regard to Gasworks Practice*, by E. W. Smith, T. C. Finlayson, H. M. Spiers, and F. S. Townend. (This paper is given in full in the Gas Journal, Coke Number, Nov. 9, 1925, pp. 3–16). *The Production of Free-Burning Solid Smokeless Fuel at High Temperatures*, by Professor R. V. Wheeler; *Combustibility and Reactivity of Coke*, by E. V. Evans; *Coke Quenching*, by D. Rider; *Coke Handling, Screening, and Breaking*, by F. M. Birks. (This paper is given in full in the Gas Journal, Coke Number, Nov. 9, 1925, pp. 47–50.)

Manufacture of Coke.—R. A. Mott, *By-Product Coke-Oven Practice* (Fuel, 1925, vol. 4, Oct., pp. 441–449; Nov., pp. 463–473; Dec., pp. 528–546). The author's survey of by-product coking practice is continued, the tenth article dealing with oven charging, coke quenching, and loading and refractories for oven construction; the eleventh, with theories of coking, coking coals, evaluation of coking power, and the coking process; and the twelfth, with fractures in coke and the path of travel of the gases in the oven.

H. W. Brooks, *The By-Product Processing of Coal* (Mechanical Engineering, Mar. 1926, vol. 48, pp. 233–239). The article gives a general outline of present-day knowledge of by-product recovery from coal, indicating the principal methods employed and the probable field of their application. Low-temperature carbonisation is dealt with at some length.

N. A. Ross, *The Mechanism of the Carbonisation of Coke in the By-Product Coke-Oven* (Gas World, 1925, vol. 83, pp. 12–14). Before the plastic stage moisture is driven off, β and γ compounds are formed by thermal decomposition of the coal and commence to decompose, and cell formation commences. During the plastic stage β and γ compounds decompose completely, the resultant gas extrudes molten γ compounds, plasticity is set up and coke structure formed. Towards the close of this stage the coke hardens. After the plastic stage the thick soft cell walls are further broken down and the remaining volatile matter is evolved with formation of the microstructure.

Tar-Distilling Plant in a Steelworks (Engineer, Jan. 15, 1926, vol. 141, pp. 68–69, 72). A new tar-distillation plant embodying many modern features has been put into commission at the works of the United Steel Companies, Ltd., in Cumberland. It is situated on a site adjacent to the coking and by-product works, on sloping ground, and advantage is taken of this circumstance for transferring the liquid products, &c., by gravity. The outstanding feature of the plant is the Hird continuous tar still unit; the wear and tear on these stills is very little, and is almost entirely confined to the firing tubes.

A. Jackson, *Metallurgical Coke* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Dec. 3, 1925, vol. 32, pp. 467–469). The distinguishing features of the open-heap, beehive, and by-product methods of coke manufacture are pointed out, and the types of coal suitable for the manufacture of metallurgical coke are briefly discussed.

L. H. Sensicle, *Coke Production* (Gas Journal, Coke Number, Nov. 9, 1925, pp. 28–34). Though dealing principally with coke production in gasworks, the paper contains a short review of by-product coking. Considerable space is also devoted to the theory of coking.

E. W. Smith and D. Rider, *The Production of Durham Coke, with Special Reference to the Becker Oven* (Paper read before the Coke-Oven Managers' Association, Jan. 30, 1926: Gas World, Coking Section, Feb. 6, 1926, vol. 84, pp. 11–15). The authors discuss the design and construction of the Becker oven. Combustion takes place in each vertical flue along one wall of the oven, the gases passing into a shallow horizontal flue through ports. The horizontal flue extends the whole length of the oven. At intervals, flues are placed which convey products of combustion over the top of the oven into another horizontal flue from which the gases pass down vertical flues on the other side of the oven into the regenerators, and finally to the chimney. Plants are operating this type of oven with widths of 13½ to 17 inches, using temperatures of about 1400° C. With strongly coking coals, where a fairly large blocky coke is to be produced, the wider ovens of about 16 inches mean width, coking in sixteen hours, are to be preferred. When, however, a blast-furnace coke of less but more uniform size is desired, the narrower oven, about 14 inches mean width, coking in twelve hours, is advantageous. A brief account of the use of Durham coals in American quick coking-ovens is included.

By-Product Plant for Shelton Iron, Steel & Coal Co., Ltd. (Colliery Guardian, Nov. 20, 1925, vol. 130, pp. 1215–1216). The equipment of the new by-product plant at Stoke-on-Trent is described and illustrated. The maximum daily output is to include 10 million cubic feet of coke-oven gas, 30 tons of tar, 12 tons of neutral sulphate of ammonia, and 2600 gallons of crude benzol, based on a yield of 3 gallons per ton of coal. The Holmes' semi-direct ammonia recovery process, upon which the plant is to operate, provides for the recovery of tar and ammonia from gas by (*a*) the partial cooling of the gas on leaving the carbonising unit by means of water-cooled condensers; (*b*) the removal of tar by means of Pelouze and Audouin extractors; and (*c*) the absorption of uncondensed ammonia by sulphuric acid.

Modernisation at Bethlehem's Lackawanna Steelworks (Iron Age, Jan. 7, 1926, vol. 117, pp. 40–45). An illustrated account of the additions and alterations made at the Lackawanna plant of the Bethlehem Steel Corporation. Two new batteries of Koppers ovens, Becker type, of fifty-seven ovens each, are operated as one unit, while sixty Solvay ovens are operated as a separate unit. The monthly capacity of the

plant is about 75,000 tons of coke. The Koppers ovens are running on a schedule of about 11½ hours between charges, and are so operated that one oven is pushed about every six minutes. The Solvay ovens have a coking time of about 16½ hours. About 40 per cent. of the gas produced is used as fuel to heat the ovens. The remainder is available for the mill furnaces, soaking pits, and open-hearth furnaces. Five new blowing engines are installed for the blast-furnaces. The washed gas is given a further washing in two Theisen washers placed in the engine-room. The No. 1 open-hearth steelworks formerly consisted of six 60-ton, and eight 100-ton furnaces. The 60-ton furnaces have been replaced by 100-ton furnaces using coke-oven gas or tar as fuel. A 600-ton mixer is also in operation.

D. P. Ross van Lennep, *Underfired Regenerative Coke-Ovens with Twin Heating Flues* (Stahl und Eisen, Mar. 4, 1926, vol. 46, pp. 294–299). An illustrated description is given of a battery of coke-ovens of the Otto type presenting several novel features. The battery is installed at one of the fiscal collieries of the Dutch Government. It consists of 126 ovens built of silica brick. There are 38 vertical flues to each oven, arranged in pairs, each communicating with its own regenerator chamber filled with checkers. Each alternate flue is heated at one time, the gases passing down through the corresponding one of the pair to the regenerator. The operation is then reversed.

D. P. Ross van Lennep, *Otto Regenerative Coke-Oven* (Iron and Coal Trades Review, Apr. 2, 1926, vol. 112, pp. 565–568). An illustrated description is given of the coking plant at the Emma Colliery of the Dutch State Mines in Limburg. The ovens are of the latest type of the "Otto" regenerative system with underfiring and twin flues.

H. Kuhn, *Results of Recent Tests on "Still" Ovens* (Colliery Engineering, Feb. 1926, vol. 3, pp. 55–61). The chief feature of the Still coke-oven is the heating arrangement. Combustion takes place in several stages, over the full height of each heating flue, instead of the usual method of combustion in one stage. The results of tests show that temperature variations in the vertical height of the oven are totally avoided.

H. Kuhn, *Heating of Modern Coke-Ovens* (Chemical and Metallurgical Engineering, Apr. 1926, vol. 33, pp. 231–234). A discussion of the variation of temperature in vertical flues of coke-ovens, and of the heat required per pound of dry coal, with special reference to the Carl Still oven.

T. Biddulph Smith, *The Application of American Practice to the British Coke Industry* (Proceedings of the Cleveland Institution of Engineers, Session 1925–26, No. 2, pp. 41–68). The author discusses the effects of varying conditions met with during carbonisation upon the quality of the resultant products. The subject is discussed under the following headings: Degree of fineness of the coal, direction of flow of gases in the oven, moisture, compression, speed of carbonisation,

width of the oven, and American practice. The following conclusions are arrived at: Narrower ovens would give better results with all coals, from the point of view of quality and product, and longer and higher ovens from the point of view of output. For good caking coals, present carbonisation temperatures should not be exceeded. For poor caking coals, high carbonisation temperatures should be used. Silica should replace quartzite only when high temperatures are absolutely necessary to produce a good coke from a poor caking coal, or where excessive salt trouble is experienced, in which latter case the carbonisation temperature should depend solely upon the caking power of the coal. The moisture content of the coal should be as low as possible. This, with poor caking coals, however, must be consistent with a good compression. The coal should be in as fine a condition as possible.

G. M. Gill, *Notes on American Gas Practice* (Gas Journal, Nov. 25, 1925, vol. 172, pp. 512–517). A paper read before the Southern Association of Gas Managers, Nov. 18, 1925. The author reviews modern American methods as applied both to gasworks and coke-oven practice.

By-Product Coke Plants Stationary (Iron Age, Jan. 21, 1926, vol. 117, pp. 224–225). By-product coke-ovens built or building in the United States on Jan. 1, 1926, are estimated to have a capacity of 50,390,275 tons of coke per annum. The number of by-product ovens is given as 11,705, of which 9242 are operated by iron and steel companies. A list is given of the number of ovens owned by each individual firm, together with particulars of types of ovens and capacity.

L. M. Wilson, *Method of Flame Propagation in Coke-Oven Flues of the Regenerative Type* (Paper read before the Coke-Oven Managers' Association: Gas World, Coking Section, Feb. 2, 1926, vol. 84, pp. 19–20). The factors governing the length of flames in coke-oven flues are discussed.

R. W. Davies, *Certain Aspects of Coke-Oven Heating in the Light of Modern Tendencies in Design* (Paper read before the Coke-Oven Managers' Association, Mar. 1926: Gas World, Coking Section, Apr. 3, 1926, vol. 84, pp. 12–16).

N. E. Rambush, *Suggested Method of Estimating the Quantity of Heat required for the Distillation of Coal* (Fuel, Jan. 1926, vol. 5, pp. 12–16).

R. Rattwinkel, *New Appliances for the Control of Coke-Oven Plant* (Glückauf, Feb. 13, 1926, vol. 62, pp. 205–208). Appliances are described for simplifying and facilitating the determination of benzene in coke-oven gas and other constituents of by-products.

M. Barash, *Scientific Control of Carbonisation, with Particular Regard to the Agglutinating Power of Coal* (Gas Journal, Coke Number, Nov. 9, 1925, pp. 17–27). The paper deals with the agglutinating power of coals and the effect produced on it by various treatments. Agglutinating power is defined as the cementing power of coal, as manifested in the production of a coherent and valuable coke on carbonising a mixture of coals of different types, which, carbonised separately, would give a non-coherent coke, or of coal with some inert material, such as coke

breeze, charcoal, anthracite dust, &c. The paper is particularly concerned with coal carbonised in gasworks.

M. Barash, *Coking of Coals* (Paper read before the Manchester section of the Society of Chemical Industry, Jan. 8, 1926: Gas Journal, Feb. 3, 1926, vol. 173, pp. 276–280).

M. J. Burgess and R. V. Wheeler, *The Initial Decomposition of Coal by Heat* (Fuel, Feb. 1926, vol. 5, pp. 65–68). Results of experiments on the thermal decomposition of a Lancashire coking coal show that whereas the gases removed under vacuum up to 200° C. appear to be occluded gases, the character of those evolved between 270° and 300° C. points to their being the products of decomposition of the coal substance.

W. P. Ryan, *Rate of Travel of Fusion Zone in Coke-Ovens* (Fuel, Apr. 1926, vol. 5, pp. 150–157). The results of an investigation show that the thermal conductivity of coke is much higher than that of coal in the various stages of carbonisation. The change in rate of travel of the fusion zone is shown and explained by the concept of heat transfer, and the cause of the influence of oven-width on coking time and daily capacity is illustrated by means of the rate of travel of the fusion zone.

E. Audibert, *The Temporary Fusion of Coals* (Revue de l'Industrie Minérale, Mar. 15, 1926, No. 126, Part I., pp. 115–136). The author has attempted to determine which of the many phenomena, which collectively constitute "cokification," were the governing factors controlling the quality of the resulting coke, in the hope that the solution of this problem would make possible the forecasting of the probable behaviour of any coal when coked by means of laboratory tests. It appeared to the author that the fusion of the coals was the principal controlling factor, and the article delineates in detail his experiments in that direction, made on coals with 10 to 12 per cent. volatiles. The author describes the fusion of coals and the mechanism involved, and shows that some of the apparent irregularities have their counterparts in the behaviour of other substances under similar conditions. He shows how the quality of the final coke is dependent on certain characteristics of the original coal and on various conditions in the actual process of coking.

G. E. Foxwell, *Determination of Temperature of Plasticity of Coal* (Industrial and Engineering Chemistry, Nov. 1925, vol. 17, p. 1161). In experiments for determining the temperatures at which coal begins to be plastic and the maximum resistance to gas flow is developed, it is necessary to fix the rate of rise of temperature. A rate of rise of 1° per minute after reaching a temperature of 300° C. gives suitable results. The coal sample should be packed in firebrick to prevent expansion.

R. K. Stockwell, *Coke Preparation* (Gas Journal, Coke Number, Nov. 9, 1925, pp. 51–62). The author deals very fully with the handling, conveying, quenching, screening, breaking, storing, and reclaiming of coke. The paper is well illustrated with photographs and diagrams of machinery in use at typical by-product furnace-coke and gasworks plants.

S. E. Whitehead, *Coke Preparation* (Gas Journal, Coke Number, Nov. 9, 1925, pp. 63–67). The paper deals with the handling by mechanical means of coke from the moment it leaves the retort until its arrival in store, and, though it refers particularly to the coke produced in a gasworks, much of the procedure is applicable to the handling of metallurgical coke.

E. C. Evans, *Short Review of Developments in Coke and Blast-Furnace Technology in* 1925 (Fuel Economy Review, Mar. 1926, vol. 5, pp. 18–25). A review of the literature published during the past year dealing with carbonisation, testing and properties of coke, and blast-furnace practice.

E. C. Evans, *Coke for Blast-Furnace Purposes* (Paper read before the Cleveland Institution of Engineers: Iron and Coal Trades Review, 1926, vol. 112, Mar. 12, pp. 425–426; Mar. 19, pp. 486–487). The author discusses the testing, properties, and preparation of blast-furnace coke. A table is given showing the coke consumption and burdens in various districts in this country as compared with figures for the United States, Belgium, Luxemburg, and Canada. The materials consumed per ton of pig iron for hæmatite, basic, and foundry and forge iron, are also tabulated. The superiority of Durham and Welsh coke, as shown in improved furnace operation, is not accounted for altogether by chemical constitution. Typical analyses of British cokes are given. Chemical analysis is of service, but, provided ash and moisture are within reasonable limits, high physical quality is probably more important than chemical analysis. To some extent physical and chemical properties are associated—thus high moisture content in coke is generally associated with physical weakness. Durham and South Wales cokes are comparatively easy to quench, so that they will not contain more than 2 per cent. of moisture, but with Derbyshire and some Yorkshire cokes it is very difficult to guarantee less than 5 per cent. moisture at the coke-oven bench. The following physical properties have been suggested as being of importance in blast-furnace operation: (1) porosity; (2) resistance to compression; (3) resistance to shatter; (4) resistance to abrasion; (5) reactivity to carbon dioxide; (6) combustibility in air or oxygen. Coal blending offers very considerable possibilities, and in a test at a Yorkshire plant an addition of a suitable quantity of non-caking coal to the coking coal generally used resulted in a reduction of coking time from thirty to eighteen hours. A very considerable increase in output per oven has been obtained in recent plants due to (*a*) more uniform heating of oven walls; (*b*) adoption of higher temperatures in the flues, and a more rapid transference of the heat to the charge due to the use of silica bricks; (*c*) introduction of the narrow coke-oven.

E. C. Evans, *The Coke Problem from the Point of View of the Iron and Steel Industry* (Paper read before the Coke-Oven Managers' Association: Gas World, Jan. 2, 1926). Despite the mechanical and structural improvements in blast-furnace design, the consumption of coal in the manufacture of British pig iron during the past forty years has remained

practically constant at from 39 to 41 cwts. per ton of metal produced. From an examination of the particulars available it appears probable that the coke produced to-day is not as good as that produced forty years ago. The properties required in a coke suitable for blast-furnace smelting are defined, and the effect of chemical impurities on fuel consumption in the blast-furnace is discussed. The importance of the physical condition of blast-furnace coke is pointed out.

The Blast-Furnace Coke Problem (Iron and Coal Trades Review, Feb. 5, 1926, vol. 112, pp. 224–225). An account of a discussion which took place before the Coke-Oven Managers' Association on Jan. 14, 1926, on the coke problem from the point of view of the iron and steel industry.

Gerhard, *The Quality of Coke and its Improvement* (Brennstoff-Chemie, July 1, 1925, vol. 6, p. 209). The possibility of producing a stronger and better coke by blending different coals is discussed.

A. D. Young, *Desulphurisation of Foundry Coke* (Proceedings of the Institute of British Foundrymen, 1923–24, vol. 17, pp. 251–261). Various methods for the removal of sulphur from foundry coke are briefly reviewed.

Structure of Coke.—H. J. Rose, *The Study of Coke Macrostructure* (Fuel, Feb. 1926, vol. 5, pp. 57–64). Methods of sectioning large coke pieces, and the grinding and polishing of their surfaces, are described. Illustrations show that cokes vary greatly in structure, and with further study it is hoped to establish a definite relationship between the structure of a coke and its combustion characteristics. The author's methods of preparing specimens will be of great value in elucidating this problem.

H. Esser and E. Piwowarsky, *The Determination of the Porosity of Coke, Refractory Materials, and Rammed Moulding Sands* (Stahl und Eisen, Apr. 29, 1926, vol. 46, pp. 565–567). A new apparatus for the determination of porosity is illustrated and described. It is claimed that by its use the making of porosity tests on various materials is simplified and reliable results are obtained. A number of examples of the application of the apparatus are given.

H. Kerr, *Coke and Coke Structure* (Paper read before the Coke-Oven Managers' Association: Iron and Coal Trades Review, Apr. 9, 1926, vol. 112, p. 613). Particulars are given of the method devised by Rose for revealing the details of coke structure. The cells and cracks of the ground and polished surface of coke are filled with plaster of Paris, thus giving an absolute contrast of white background against the black material of the coke substance. Owing to the varying degree of polish taken by the different constituents in the coke these come out in more detail, the surface lending itself for macro- or micro-examination.

Combustibility of Coke.—C. Holthaus, *Influence of the Chemical and Physical Properties of Coke on the Combustibility* (Stahl und Eisen, Jan. 14, 1926, vol. 46, pp. 33–39). Samples of coke from four collieries

in the Dortmund district were taken for purposes of the investigation, each kind of coke being represented by three samples cut from the outside, the centre, and the intermediate between outside and centre of the finished mass of coke in the oven. All the samples were tested as regards ash content, silica, porosity, compressibility and friability, ignition point, and gas content. The ash in all samples averaged 10·3 per cent., ranging from about 11·10 in those from nearest the oven wall to about 9·80 per cent. in centre samples. The silica in the ash averaged 4 per cent. Various methods for determining the porosity were tried, the most trustworthy results being obtained by the gravimetric method. As might be expected, the coke nearest the oven wall showed a greater density than that from the centre. The compressibility was tested in a lever press and the friability according to Schmolke's method, which consists in grinding a coke sample of any shape on an emery wheel, under constant load and constant speed, and measuring the loss of weight in grammes. Ignition tests were made on finely powdered coke and on coke crushed to a size of 0·3 to 0·5 millimetre. In all cases the temperature of ignition was higher with the larger size, the difference being dependent on the structure of the coke. In one case the ignition point was 640° C. for the powdered, and 649° C. for the crushed; in another it was 650° and 680° C. respectively. Several methods were followed for determining the combustibility, which is expressed as the percentage of the carbon dioxide converted to carbon monoxide (0·0 per cent. CO_2 = 100 per cent., or 21 per cent. CO_2 = 0·0 per cent. combustibility), and the combustibility of the samples was found to range from 20·5 to 34 per cent. It is concluded that no regular relation between any of the coke properties and its combustibility can be traced except in a few isolated instances. Some kind of relation must exist, but the lack of homogeneity of the coke vitiates the results of the experiments.

R. A. Sherman and S. P. Kinney, *Combustibility of Blast-Furnace Coke* (Fuel, Mar. 1926, vol. 6, pp. 98–105). Experiments to determine the temperature of combustion of coke show that those factors commonly believed to affect the combustibility of coke in air, namely, character of coal, coking process, coking time, density, porosity or volatile content, have no apparent material relation to the combustibility as measured in the experimental furnace or in the blast-furnace hearth. The only factor which has any appreciable effect on combustibility is that of size. To correlate results of laboratory tests is extremely difficult, and an investigation in a blast-furnace is needed.

R. H. Sweetser, *What is "Combustibility of Coke"?* (Iron Age, Feb. 18, 1926, vol. 117, pp. 477–478). Calls attention to the misunderstanding between technical investigators and blast-furnace men as to the meaning of the words "combustibility of coke." It is not sufficient to compare the combustibility of different cokes in a laboratory when ground so fine that all the particles are easily exposed to the hot air or gases. The combustibility of different cokes must be compared under

the conditions which exist in those cokes when delivered to the blast-furnace. According to T. L. Joseph, a fast-burning coke will burn in a more restricted volume than a slow-burning coke. This conclusion is not in agreement with that of S. P. Kinney, who states that the extent of penetration of the combustion zone at the tuyere level of the blast-furnace is constant, not depending upon the amount of air blown. Kinney's statement is confirmed by the author, who gives two charts, which prove conclusively that the size of the combustion zone is not dependent upon the quantity of coke consumed in a given time. Of the recently published papers on the combustibility of coke in the blast-furnace, the one, that in the author's opinion, seems most correct in its conclusions is that of Sillars, read before the West of Scotland Iron and Steel Institute on Feb. 20, 1925. In this paper Sillars states that combustibility is a measure of the speed of the combination of oxygen and carbon to form carbon monoxide. The author puts forward the following definition of combustibility of coke: "The combustibility of a blast-furnace coke is the rate of complete gasification of that particular coke in front of the tuyeres of a blast-furnace under standard conditions of blast temperature and of blast volume."

Bunte, *Reactivity of Coking Products* (Brennstoff-Chemie, 1925, vol. 6, pp. 294–295). It is shown that the reactivity of a coke largely depends on its specific surface, and as a measure of this factor the capacity of the coke to adsorb carbon dioxide was used. A connection between the power of adsorption and the ignition temperature was observed, but it was not possible to express it in definite terms.

W. W. Hollings, *Notes on the Combustibility of Coke and Direct Reduction in the Blast-Furnace* (Paper read before the Iron and Steel Institute, June 1925: this Journal, p. 285).

D. J. W. Kreulen, *Importance of the Combustibility of Coke for Firing Boiler Furnaces with Solid Fuel* (Brennstoff-Chemie, 1926, vol. 7, pp. 54–57). Within limits the temperature of a coke fuel bed on a grate increases with the decrease of its thickness, and there is an optimum thickness, depending on the quality of the coke, for the production of the maximum heat.

L. Korevaar, *American and French Work on the Combustibility of Coke* (Fuel, Mar. 1926, vol. 6, pp. 92–97). The work of Sherman and Kinney and of Arend and Wagner on combustibility tests is reviewed.

J. P. Arend and J. Wagner, *The Reactivity of Coke* (Fuel, Mar. 1926, vol. 5, pp. 106–116). The article is a translation in full of the authors' paper published in 1924 (Revue de Métallurgie, 1924, vol. 21, p. 585).

R. V. Wheeler, *Coke for Crucible Steel Melting* (Paper read before the Sheffield Society of Engineers and Metallurgists: Iron and Coal Trades Review, Apr. 23, 1926, vol. 112, pp. 696–697). The qualities sought for in steel-melting cokes relate essentially to their mechanical properties and to their manner of burning. Whilst it is desirable that

the coke should contain but little moisture, ash, and sulphur, not so much stress is laid upon its chemical composition as on its physical properties. Preference is shown by steel-melters for beehive coke. The chief difficulty ascribed to the use of by-product coke lies in the troublesome clinker, which sticks to the furnace linings and to the pots, and greatly increases the labour involved in working the pot-holes. The physical characteristics which impart to the coke those qualities desired by the steel-melter are discussed.

Low-Temperature Carbonisation.—*Low-Temperature Carbonisation* (Report of Fuel Research Board, 1924, pp. 34–43). Crushed and blended coals were carbonised up to 650° C. without previous briquetting in cast-iron vertical retorts such as are used in Scottish shale practice. A satisfactory smokeless fuel and a reasonable yield of oil were produced. The amount of breeze was not excessive.

C. H. Lander, *Low-Temperature Carbonisation* (Fuel Economy Review, Mar. 1926, vol. 5, pp. 10–13). Developments in the low-temperature carbonisation of coal are reviewed.

J. Roberts, *Coal Carbonisation* (Colliery Engineering, 1924, vol. 1, Sept. pp. 305–308, Oct. pp. 357–359, Nov. pp. 438–441, Dec. pp. 470–472, 475; 1925, vol. 2, Jan. pp. 9–11, Feb. pp. 53–55, Mar. pp. 127–130, May, pp. 202–205, June, pp. 267–269, Nov. pp. 514–518, Dec. pp. 566–567; 1926, vol. 3, Jan. pp. 37–39). A series of articles dealing with both high- and low-temperature carbonisation. The subject is dealt with under the following headings: Rationale of coking and non-coking coals, their classification and behaviour during carbonisation; principles of coal carbonisation; low-temperature carbonisation; rotary retorts, producer-type retorts, conveyor-retorts; coke-oven practice; evolution of by-product oven; manufacture of semi-coke; modern types of coke-ovens.

D. Brownlie, *Low-Temperature Carbonisation* (Proceedings of the South Wales Institute of Engineers, 1926, vol. 42, pp. 273–376). The author discusses the processes for the production of free-burning smokeless fuel, involving the mechanical compression or briquetting of the charge before or during carbonisation. The subject is dealt with under the following sections: (1) Mechanical compression of the viscous charge during carbonisation. (2) Briquetting by means of a pitch or other externally produced binder, followed by carbonisation. (3) Briquetting without pitch or other externally produced binder, followed by carbonisation.

D. Brownlie, *Low-Temperature Carbonisation* (Transactions of the Institution of Mining Engineers, 1926, vol. 71, pp. 181–247; Iron and Coal Trades Review, 1926, vol. 112; Feb. 26, pp. 348–349; Mar. 5, pp. 392–393; Mar. 12, pp. 450–451; Mar. 26, pp. 534–535; Apr. 2, pp. 576–577). The author gives a comprehensive survey of different processes of low-temperature carbonisation operated in direct conjunction with steam boiler, general furnace and power plants, especially in relation

to the utilisation of low grade colliery fuels. The term "low-temperature carbonisation" is applied in the broadest possible manner, and covers the treatment of coal and other carbonaceous matter by methods involving heat treatment in a manner different from existing high-temperature carbonisation methods so as to extract the maximum amount of valuable by-products, especially oils, and to deliver either solid residual smokeless fuel or gas in a condition more suitable for general utilisation than raw coal or high-temperature coke. Steam generation is a particularly suitable operation for the application of combined low-temperature carbonisation and fuel consumption so long as fairly large water-tube boilers are employed to give a sufficient rate of coal consumption per individual unit. The subject is discussed under the following headings: (1) The pre-drying of raw fuels before combustion, carbonisation, or gasification. (2) Low-temperature carbonisation in conjunction with mechanically fired furnaces. (3) Low-temperature carbonisation in conjunction with pulverised fuel firing.

S. McEwen, *Carbonisation of Pulverised Fuel at Low Temperatures* (Combustion, 1926, vol. 14, p. 107). After carbonisation of powdered coal in a retort the product is withdrawn in the form of a finely divided semi-coke, which is superior to powdered raw coal for combustion in a furnace. It does not cake, is not liable to spontaneous combustion, and the particles being hollow, the rapidity of combustion is increased.

C. Dantin, *Recent English Experiments on the Carbonisation of Coal with High Production of Liquid Hydrocarbons* (Génie Civil, Mar. 20, 1926, vol. 88, pp. 277–279). A description of the plants of the Low-Temperature Carbonisation Company at Barugh and of the Midland Coal Products Company at Netherfield.

C. Demeure, *Low-Temperature Carbonisation in England* (Annales des Mines de Belgique, 1925, vol. 26, Part 4, pp. 1201–1261). The author, in his introduction, discusses the relative advantages of the Bergius and low-temperature carbonisation processes from the point of view of British needs. The former converts practically the whole of the coal into liquid fuels, but the latter is not only cheaper, but while yielding less liquid fuels produces a solid fuel for which there is a great domestic and industrial demand. The author describes his visits to the Fuel Research Board's station at East Greenwich, the Maclaurin Works at Dalmarnock, and the Midlands Coal Products, Ltd., near Nottingham, and reports in detail his investigations of the work carried out, from the practical and commercial as well as the scientific point of view. He also visited the works of the Sensible Heat Distillation Co., Ltd., and the Low-Temperature Carbonisation Co., Ltd., at Barnsley, and others at Pontypridd (Illingworth), Bradford (Hird), and Middlewick (Hutchins), and the account of his investigations at these places will be published later.

H. Verdinne, *On the Low-Temperature Carbonisation of Solid Fuels* (Revue Universelle des Mines, Dec. 1, 1925, vol. 8, pp. 296–306). A

consideration of the aim and object of low-temperature carbonisation, and of the difficulties encountered in practice. The action of too high a temperature in producing coke, gas, and heavy oils, and the underlying chemical reactions, are discussed. The fuels available, together with the products obtained from them, and the fractionation of the primary tar are also considered. Many references are made to British experimental work and practice.

S. W. Parr, *Relation of Origin and State of Carbonisation of Coal to Problems of Low-Temperature Carbonisation* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926).

M. W. Ditto, *Low-Temperature Distillation of Coal* (Year-Book of the American Iron and Steel Institute, 1925, pp. 225–250). The author discusses the development of low-temperature distillation and describes various processes.

S. R. Church, *Relation of Tar Utilisation to Coal Carbonisation*, (Chemical and Metallurgical Engineering, Nov. 1925, vol. 32, pp. 869–870). A review of the disadvantages of low-temperature carbonisation. There is a steadily increasing demand for smokeless household fuel in America and Canada, and the author is of opinion that a "medium temperature" carbonisation process will produce the required smokeless fuel and at the same time yield by-products of greater value than those produced by low-temperature processes.

W. H. Blauvelt, *Low-Temperature Carbonisation as a Commercial Process* (Chemical and Metallurgical Engineering, Dec. 1925, vol. 32, pp. 925–927). A discussion of the probable market for the smokeless fuel, high heat value gas and tar oils, produced by low-temperature carbonisation.

The Hird Low-Temperature Carbonisation Process (Fuel Economist, Nov. 1925, vol. 2, pp. 97–98).

E. K. Scott, *The Manufacture of Smokeless Fuel: The Maclaurin Process* (Combustion, Dec. 1924, vol. 11, pp. 438–440). A description of the Maclaurin retort. By regulating the amounts of air and steam admitted to the retort, the products obtained may be a black smokeless fuel and a certain quantity of gas, a grey coke and more gas, or a grey cindery residue with a maximum quantity of gas. The retort resembles in some detail a gas-producer, but the tar condenser at the top and the bottom discharge arrangements distinguish it from other forms of producer.

Low-Temperature Carbonisation at Glasgow (Colliery Engineering, Dec. 1925, vol. 2, pp. 546–553). An illustrated description is given of the Maclaurin low-temperature carbonisation plant in operation at the Dalmarnock Gasworks, Glasgow.

The Raffloer Low-Temperature Carbonisation Retort (Iron and Coal Trades Review, Feb. 5, 1926, vol. 112, p. 223). Illustrated particulars are given of the design of the Raffloer rotary retort. Finely crushed bituminous coal is made to travel the length of the retort in a longitudinal cell or groove in which it is converted by compression and the

temperature in the retort into a solid, compact body, which at the discharge-end is cut into bricks of convenient size by a special apparatus. The retort is heated externally by gas. The process is regarded as a combination of a low-temperature carbonising process with by-product recovery and briquetting.

E. Marcotte, *The Low-Temperature Carbonisation of Lignites at the Laluque Mines, Landes, France* (Génie Civil, Mar. 13, 1926, vol. 88, pp. 245–250). The Tozer system of low-temperature carbonisation is employed.

A. Thau, *Low-Temperature Distillation as a Preliminary Stage in Coking* (Glückauf, Jan. 2, 1926, vol. 62, pp. 1–11). The advantages of installing a low-temperature retort to work in conjunction with coke-ovens are discussed. Special reference is made to the Salerni retort working in connection with coke-ovens at the Heinitz colliery in the Saar district.

A. Thau, *Low-Temperature Carbonisation in Revolving Retorts* (Blast-Furnace and Steel Plant, Nov. 1925, vol. 13, pp. 434–441). A very full description of a low-temperature carbonisation plant built by the Fellner and Ziegler works to the designs of Dr. N. Young, and now in operation at Gelsenkirchen. Much information concerning the raw materials and the products obtained is also given.

A. Thau, *Low-Temperature Process Produces Hard Coke* (Chemical and Metallurgical Engineering, Apr. 1926, vol. 33, pp. 227–228). A description of the Dobbelstein retort, its operation and its products.

Geissen Retort for Low-Temperature Distillation of Coal (Glückauf, Mar. 27, 1926, vol. 62, pp. 408–410). An illustrated description of the apparatus is presented, with full results of working on brown-coal. It is intended primarily for treating non-caking coals, and in view of its success in distilling brown-coal its use is likely to be extended to hard coal.

J. Sommermeier and R. H. Gummer, *The Carbonisation of Fuel at Low Temperature* (Fuel Economist, Oct. 1925, vol. 1, pp. 37–45). A description is given of the K.S.G. International Stinnes process in operation in Germany.

Sensible Heat Distillation (Gas Journal, Dec. 9, 1925, vol. 172, pp. 654–656). A description of the "L. and N." process and plant erected for demonstration purposes at Barugh by Messrs. Sensible Heat Distillation, Ltd. The retort is a firebrick-lined cylinder, about 45 feet long by 3 feet outside diameter, rotating slowly on its axis, which is slightly inclined to the horizontal. The coal is fed in continuously at the upper end, and as it travels slowly down the retort it meets a current of hot gaseous distilling medium. This latter may be the products of combustion of producer-gas with secondary air; straight producer-gas carrying its sensible heat from the producer; superheated water-gas, or a reheated circulating gas. The choice of distilling medium depends on circumstances. The solid product of the process when using Barnsley Bed coking smalls is a semi-coke.

J. Sainte-Claire Deville, *Researches Undertaken at the Saar Mines on Low-Temperature Carbonisation* (Paper read before the Fourth Congress of Industrial Chemistry at Bordeaux, 1924: Chimie et Industrie, Feb. 1926, vol. 15, pp. 163–172). A description of the small and large scale experimental plant, and of the results obtained. The author suggests that low-temperature carbonisation will play a large part in decreasing the amount of liquid fuels which the Central European countries have to import, by providing them with suitable fuel oils from their own coals.

H. Nielsen, *Notes on the Exothermic Reactions of Bituminous Coals at Low Temperatures* (Gas Journal, Jan. 27, 1926, vol. 173, pp. 202–204). Experiments were made in which solid lumps of coal, cut and ground to a cubic shape, were heated to temperatures of 150°, 200°, and 250° C., while thermometers were inserted in holes drilled in various positions. After some time the temperature nearer the centre of the block began to overtake those nearer the outside, indicating that exothermic reactions were taking place; this occurred even at so low a temperature as 150° C. It was found that the volatile matters had lost weight approximately equal to that gained by the fixed carbon, that is, the coal had been upgraded. The effect was more marked in the younger coals. The curves indicating the temperature drop through the coal-mass emphasise the advisability, when distilling by internal heat, of using small coal.

Carbonising and Gasifying; Modern Fuel Technology (Zeitschrift des Vereines Deutscher Ingenieure, Special Number, 1925, vol. 69, 166 pp.). Contains papers by a number of leading German fuel technologists, dealing with the preparation of coal, brown-coal and peat, gas production, long-distance distribution of gas, carbonisation at high and low temperatures, constitution of coal, liquefaction, and other matters.

D. Brownlie, *Coal Blending—A Review of General Principles as Applied both to High- and Low-Temperature Carbonisation* (Paper read before the Iron and Steel Institute, June 1926: this Journal, p. 229).

R. K. Stockwell, *Coal Blending* (Gas Journal, Dec. 9, 1925, vol. 172, pp. 649–650). The Robins measuring coal mixer is described and illustrated; the various coals to be mixed are broken to 1¼-inch size and put into separate hoppers from which belt conveyors continuously withdraw the coal in the proportions that are required. Safety devices are fitted so that should the mixing become faulty the whole machine stops. The Bradford breaker is also illustrated and described; this breaks up the run-of-mine coal to the desired sizes and at the same time removes all foreign matter, so improving the quality of the resultant coke.

IV.—*LIQUID FUEL.*

Australia.—Wade, *Report on Petroleum Investigations made in New South Wales* (Melbourne, 1925). An account is given of the kerosene shale deposits, with special reference to the Wolgan Valley Works.

Canada.—C. C. Ross, *Petroleum and Natural Gas Development in Alberta* (Bulletin of the Canadian Institute of Mining and Metallurgy, Apr. 1926, No. 168, pp. 466–495).

Roumania.—A. Rabischon, *The Petroleum Reserves of Roumania* (Rassegna Mineraria, 1925, vol. 58, pp. 94–96).

United States.—F. D. Gore, *Oil Shale in Santa Barbara County, California* (Bulletin of the American Association of Petroleum Geologists, 1924, vol. 8, pp. 459–472).

Western Hemisphere.—A. J. Kraemer and L. P. Calkin, *Properties of Typical Crude Oils from the Producing Fields of the Western Hemisphere* (United States Bureau of Mines, 1925, Technical Paper No. 346). The report includes comments, tabulated data, and analyses of typical crude oils from the producing districts of Canada, Mexico, Trinidad, Venezuela, Argentina, Colombia, and Peru. For purposes of comparison analyses of crude oil from the chief districts of the United States are included.

World's Petroleum Resources.—E. Marcotte, *The Economic Problem of Liquid Fuels* (Arts et Métiers, Dec. 1925, vol. 78, pp. 473–490). A survey of the world's oilfields, their present production and future prospects. The situation as it affects France is discussed. Some of the methods used for winning the oil are described.

Treatment of Oil Shales.—F. G. Green, *Adoption of Gas-Producer Practice in the Retorting of Oil Shales* (Canadian Chemistry and Metallurgy, 1925, vol. 9, pp. 185–186). The author discusses briefly the gas-producer type of retort, and gives notes on the characteristics of different retorts and operating conditions.

F. Giordani, *Furnace for the Distillation of Bituminous Shale* (Annali di Chimica Applicata, 1925, vol. 15, pp. 273–283). Furnaces such as those used in Scotland and Germany for the distillation of oil shale are unsuitable, on account of their high fuel consumption, for the treatment of low-grade ichthyolic bituminous shales of Giffoni Vallepiana in Italy. For these a furnace has been designed composed of three zones, the upper having the smallest and the lowest the largest cross-section, and the method of its operation is described.

S. F. Shaw, *Possibilities of Shale Oil* (Engineering and Mining Journal-Press, Dec. 12, 1925, vol. 120, pp. 929–930). A report, formulated by the American Petroleum Institute, of an inquiry made into the recovery, prices, and costs of oil shale mining in America. It would appear unlikely that an extensive industry can be built up in the near future on the basis of present reserves.

Distillation of Coal.—A. C. Fieldner and R. L. Brown, *The Complete Utilisation of Coal and Motor Fuel* (Blast-Furnace and Steel Plant,

Feb. 1926, vol. 14, pp. 138–140). The authors express the opinion that, so far as America is concerned, coal will outlast the supplies of petroleum, and they review the various methods by which motor fuel may be obtained from coal.

V. Neveux, *The Distillation of Lignites for the Production of Oils and Petrols* (Génie Civil, Oct. 17, 1925, vol. 87, pp. 321–326). A description is given of the lignite distillation plants at Castellina in Chianti, Italy, and at La Caunette in Hérault, France.

Refining Petroleum.—L. Burgess, *Chlorine in the Petroleum Industry* (Paper read before the American Electrochemical Society, Apr. 1926). The present uses of chlorine in the petroleum industry are briefly described and possible extensions are indicated.

Hydrogenation of Coal.—F. Bergius, *The Liquefaction of Coal* (Zeitschrift des Vereines Deutscher Ingenieure, Oct. 24, 1925, vol. 69, pp. 1359–1362). The author concludes his article on the subject (see this Journal, 1925, No. II. p. 396). He shows that the only raw material required for the process of liquefaction is coal. Coal is used for the reaction, for heating, and for generating the power. The hydrogen can always be recovered from the gas resulting from the reaction.

F. Bergius, *Liquefaction of Coal* (Glückauf, 1925, vol. 61, Oct. 17, pp. 1317–1326; Oct. 24, pp. 1353–1358). Another account of the investigations described in the foregoing abstract.

D. G. Skinner and J. I. Graham, *Hydrogenation and Liquefaction of Coal. III.—Hydrogenation of Brown-Coal, of Devonshire Lignite, and of Low-Temperature Coke Obtained from Devonshire Lignite* (Fuel, Nov. 1925, vol. 4, pp. 474–485). A German brown-coal, two Devonshire lignites, and semi-coke prepared from the last two at 440° were mixed with twice their weight of phenol, and were subjected to hydrogen pressure under about 120 atmospheres at about 415° for eight to twelve hours. The resulting products were extracted from the autoclave, and all the phenol soluble products were removed. The ash content does not appear to affect the result much, and the observation that the yield of oil is increased by the presence of water is substantiated. Bergius' claim that complete conversion of a coal can be obtained if its carbon content is less than 85 per cent. is not confirmed, but the conditions of hydrogenation in the presence of gas were less drastic than those used by Bergius. The yield of distillate, following the ordinary conditions of hydrogenation, varied from 14·4 per cent. liquid distillate from German brown-coal up to 28·2 per cent. from recent lignite from Heathfield.

J. I. Graham, *The Conversion of Coal into Oil by Hydrogenation* (Transactions of the Institution of Mining Engineers, 1925, vol. 70, pp. 86–106). The author reviews previous work on the action of hydrogen on coal up to 200 atmospheres at 300°–450° C., and describes the experiments carried out in the Mining Research Laboratory of the University of Birmingham. These include a study of the action of

steam on bituminous coals under high pressure, to ascertain at what temperature very finely divided coal begins to react with water under the conditions involved by treatment in an autoclave.

Use of Petroleum.—A. F. Baillie, *The Commercial Application of Fuel Oil* (Paper read before the Institution of Engineers and Shipbuilders in Scotland, Dec. 1925). The author refers to the results obtained by an Italian firm using fuel oil for heating four basic open-hearth furnaces of 65 tons capacity. The furnaces are fitted with five charging doors, and each section is built on the separate arch principle. The furnaces are charged with molten pig iron. The temperature obtained is 1650° C., and an output of 150 tons per twenty-four hours per furnace is obtained on an oil consumption of from 16·5 to 18·75 tons.

M. H. Mawhinney, *Oil-Burning Equipment for Industrial Furnaces* (Transactions of the American Society for Steel Treating, Jan. 1926, vol. 9, pp. 99–110). The author reviews the installation and operation of oil-burning equipment, including storage tanks and auxiliary equipment. The chief difficulties encountered in supplying oil fuel to the furnace are dealt with in a general way.

M. Sklovsky, *Research in Liquid Fuel Economy* (Year-Book of the American Iron and Steel Institute, 1925, pp. 300–318). The author discusses the results of an investigation of the economical use of fuel oil in metallurgical furnaces. The investigation, which began in 1921, shows a wide variation in the efficiency of the various types of furnaces. The subjects under discussion are—the influence of temperature, the factors of temperature, control of excess air, effect of gasification, and furnace construction.

W. F. Schafhorst, *Efficiency of Oil-Fired Boilers* (Blast-Furnace and Steel Plant, Sept. 1925, vol. 13, p. 375). A chart is presented by which the efficiency of a boiler may be read off from a knowledge of the temperature of the chimney gases and of the heat value of the oil. With a little alteration the chart can be made applicable to any other fuel.

V.—*ARTIFICIAL GAS.*

Gas-Producers.—*The Wellman "L" Type Gas Machine* (Iron and Coal Trades Review, Nov. 13, 1925, vol. 111, pp. 778–779). Illustrated particulars are given of the construction and operation of a new type of Wellman gas-producer. The producer is entirely automatic from coal feed to ash removal, and is fitted with an oscillating water-cooled mechanical poker, an intermittently rotating ash-pan, and a three-port steam jet blower. It is made in two sizes—one with a gasifying capacity of from 1500 to 2750 lbs., and the other from 2500 to 4000 lbs. of bituminous coal per hour.

A. Grebel, *Strache Gas-Producers in the Gas Industry* (Génie Civil, Oct. 31, 1925, vol. 87, pp. 368–373). The Strache producer is illustrated and described.

F. Kaiser, *Experiments on a New Low-Temperature Tar-Recovery Gas-Producer and Plant* (Braunkohle, 1925, vol. 24, pp. 673–678, 699–704, 718–724). A detailed description is given of a by-product gas-producer for brown-coal briquettes, and its accessory equipment. Operating tests are also included.

A. Robinson, *Notes on Producing Gas* (Proceedings of the Lincolnshire Iron and Steel Institute, 1918–1920, vol. 1, pp. 134–139). Tabulated data are given of the operating results of brick-lined and water-jacketed producers, showing the effects of variations in the amount of steam introduced into the producers, heat losses during the cleaning-out period, and heat losses due to the water circulated through the water-jacketed producers.

Producer Practice.—H. R. Trenkler, *The Influence of Mechanical Action on the Fuel on the Gas-Producer* (Zeitschrift des Vereines Deutscher Ingenieure, Dec. 12, 1925, vol. 69, pp. 1549–1556). The chemical processes involved in the gasifying of fuel are first considered, after which the author deals with the mechanical principles of the various types of producers and the manner in which the gasification is affected by the different actions of the mechanical parts.

G. Husson, *A Contribution to the Study of the Gas-Producer* (Revue de l'Industrie Minérale, Mémoires, Oct. 15, 1925, pp. 451–472). A discussion of the physical and chemical reactions occurring in a gas-producer. No comparison of types is made; only the results of the manipulation of the producer are considered, and the question of construction is not gone into at all.

H. K. Seeley, *Developing a Water-Gas Process using Bituminous Coal* (Chemical and Metallurgical Engineering, Apr. 1926, vol. 33, pp. 218–220). Blowholes and a large zone of uncarbonised material are the two principal difficulties encountered in the use of large producers consuming bituminous coal. Research proved ultimately that these troubles were due to the fact that bituminous coal cannot store up in itself sufficient heat during the "blast" to decompose the air and steam during the "run," and the extra heat necessary for this is supplied by the walls of the producer. A solid pier in the centre of the producer forms another "wall" capable of absorbing additional heat, and its use enables larger producers to be run on bituminous coal without the admixture of coke or anthracite.

G. R. McDermott, *The Application of Blast-Furnace Gas and Air for Blowing a Gas-Producer* (Blast-Furnace and Steel Plant, Sept. 1925, vol. 13, pp. 344–346). Experiments were made to attempt to replace the steam used in gas-producers by blast-furnace gas. Merely mixing the air and gas proved ineffective, and the producer clinkered badly and made bad gas. Alternate blows with air and gas gave much better

results, the relative periods being proportioned to give maximum efficiency. Heat balances are set out in the article, and from these it is calculated that the total saving of coal on the producer was 20 per cent.

F. Muhlert, *A New Process for Cooling Poor Gases with Recovery of the Heat* (Chaleur et Industrie, Dec. 1925, vol. 6, pp. 575–576). The information is taken from an article by J. Fabian, which appeared in Zeitschrift für Angewandte Chemie, No. 22, 1925. The temperature of the gases issuing from producers using lignite briquettes is low, and frequently does not exceed 80° C.; surface cooling then becomes impossible. In the process described water is sprinkled into the gas in the usual counter-current manner, and the warmed water is then caused to trickle through the air for the blast, preheating it and saturating it with water vapour.

N. E. Rambush, *Producer-Gas* (Fuel Economy Review, Mar. 1926, vol. 5, pp. 13–17). A review of the developments in gas-producer practice during 1925.

Use of Gas for Industrial Heating.—E. R. Weaver, *The Relation between Heating Value of Gas and its Usefulness to the Consumer* (United States Bureau of Standards, 1925. Technologic Paper No. 290). This paper contains a critical review of available data regarding the relative usefulness of gases of different heating value. The sources of information are limited to published data, and official reports which have been submitted to various American public bodies.

The Use of Gas in Industrial Heating Processes (Engineering, Jan. 22, 1926, vol. 121, p. 105). A brief account of a paper on "Industrial Gas Firing," read by A. Docking at a meeting of the Belfast Association of Engineers on Jan. 21, 1926. Coal-gas has many advantages, such as its freedom from ash, uniform quality and heating capacity, cheapness, and the small amount of labour it requires. For low temperatures the ordinary type of Bunsen-burner is quite efficient, but for higher temperatures, or in cases where constant conditions of heating are required, other systems of burning the gas have been found necessary. The use of high-pressure gas, or separate gas and air blast, have certain disadvantages, and to overcome these the gas and air mixture system has been introduced. The gas passes through an "incorporator," where it is mixed at atmospheric pressure with the incoming air, sensitive valves controlling the gas inlet and the outlet pressure. The mixture can be varied at will, but the mechanism is so arranged that a weaker mixture than one volume of gas to two of air cannot be made, the mixture delivered being always perfectly safe to use. The gas is passed to the service pipes through the control valve by means of a multi-bladed compressor, resulting in a constant pressure and a uniform mixture. It is claimed that this system surmounts the difficulty of "stratification" which occurs when high-pressure gas is supplied direct to the burner, and also the demands for gas in other

parts of the works have no effect on the exact adjustment of the mixture.

F. Plenz, *The Processes of Combustion as a Foundation for the Industrial Uses of Gas* (Gas- und Wasserfach: Gas World, Jan. 23, 1926, vol. 84, pp. 81–82). For high temperatures excess of either gas or air should be avoided. Hydrogenous gases give the highest temperatures, but their use requires burners of good construction, and the gas-air mixture should be passed in at high velocities so as to obviate back-firing. It is important to have a uniform gas supply as regards quality and specific gravity of the gas, and to have a sufficient and uniform pressure.

C. H. Smoot, *Combustion Control by Machinery* (Iron and Steel Engineer, 1925, vol. 2, pp. 286–291). The author's system of controlling combustion applied to gas distribution in a blast-furnace plant is described and illustrated. Particulars are also included of combustion control in a hot-blast stove and a gas-fired boiler.

F. W. Sperr, *Purification of Open-Hearth Gas Fuel* (Blast-Furnace and Steel Plant, Mar. 1926, vol. 14, pp. 146–148). The principal impurity to be removed from the fuel gas is sulphuretted hydrogen. The dry process, which is standard practice to-day in gasworks, uses hydrated iron oxide, but this system requires a very large ground area. The Koppers Company's system, which is described in the article, employs a wet method, the sulphuretted hydrogen being absorbed in a dilute solution of soda ash.

C. Berthelot, *Wet-Scrubbing of Coal-Gas* (Chimie et Industrie, Nov. 1925, vol. 14, pp. 663–678). A discussion of the methods of gas-scrubbing and the technical and other difficulties to be overcome in connection with coke-oven gas as well as town's gas. An American process using a soda solution is considered, with a view to determining its suitability to conditions as they exist in France. The question of cleaning the gas at the coke-oven plant or at the local gasworks when the latter is far removed from the former is debated, and the verdict given in favour of scrubbing at the coke-ovens. The author points out that the use of coke-oven gas in place of town's gas is very behindhand in France as compared with other countries, but adds that progress in that direction is now beginning to be made.

J. Fallon, *Furnaces* (Paper read before the Midland Junior Gas Association, Jan. 21, 1926: Gas Journal, Feb. 3, 1926, vol. 173, pp. 281–283). The author demonstrates the efficiency of town's gas as a fuel for industrial heating. The cost of fuel per hour or per shift is not the controlling factor in calculating the total cost for any furnace; thus town's gas, though showing a high fuel cost, can in many cases prove more economical, because, by its use, the stand-by losses and the maintenance and labour losses are lower, and the interest on investment is less.

H. Hartley, *Industrial Uses of Town's Gas* (Fuel Economy Review, Mar. 1926, vol. 5, pp. 46–51). A review of developments in the appli-

cation of town's gas to industrial furnaces, including the melting and heat treatment of metals.

Use of Blast-Furnace Gas.—W. Tafel and F. Anke, *The Possibility of the Use of Blast-Furnace Gas in the Siemens-Martin Furnace* (Stahl und Eisen, Oct. 22, 1925, vol. 45, pp. 1773–1777). The authors are of opinion that straight blast-furnace gas can be applied to the heating of open-hearth furnaces, but it becomes necessary to enlarge considerably the regenerators, and also the burnt gases must be cooled down to 225° C. in the regenerators in order to preheat sufficiently the incoming gas and air. If the burnt gases are not cooled so far, then the furnace must be heated more strongly—that is to say, each ton of steel consumes more heat units. In this latter case it is not only necessary to enlarge the regenerators, but to alter the measurements of the burners, and other disadvantages arise, such as bad mixing of the entering gas and air and a very high velocity of exit of the products of combustion, with consequent marked burning away of the crown. The above considerations explain why blast-furnace gas has hitherto failed in the open-hearth furnace unless mixed with some other gas of higher calorific value.

T. Thomson, *Notes on the Economical Use of Blast-Furnace Gas* (Proceedings of the Lincolnshire Iron and Steel Institute, 1918–1920, vol. 1, pp. 140–151). The author has investigated the various uses to which blast-furnace gas should be put in order to give the greatest economy. The possible methods of utilising the gas in iron and steel plants are compared, and an estimate is given of the cost of each method.

J. Lilot, *Combustion of Blast-Furnace Gas* (Revue Universelle des Mines, Feb. 15, 1926, vol. 9, pp. 188–190). The author shows how, by burning blast-furnace gas with the theoretically correct proportion of air, the CO_2 in the waste gases attains a maximum. He suggests that when burning such gas a CO_2-recorder should be fitted in the flue, and the furnace run in such a way as to yield the highest possible amount of CO_2, thereby obtaining maximum efficiency.

Gruhl, *Electric Purification of Gases* (Zeitschrift für Angewandte Chemie, 1925, vol. 38, p. 565). The author reviews the various methods in use for cleaning gas and describes electrical precipitation.

Gas-Engines.—G. Stauber, *Wet Gas-Turbines* (Stahl und Eisen, Nov. 26, 1925, pp. 1937–1958). A full description, with many detailed drawings, is given of a new type of turbine. The rotating part consists of a hollow piston, partly filled by a volume of water, in contact with power gas. The water is caused to oscillate by explosions produced by ignition of the gas, the impulses imparting a rotary motion to the piston. The aim of the designer has been to produce a prime-mover at not more than one-fifth of the cost of a reciprocating gas-engine and of greatly simplified construction, and with an efficiency of not more

than 20 per cent., the idea being that there is in many works, such as ironworks, a great surplus of power gas, for the utilisation of which it is far more economical to install cheap power plant than to aim at a high degree of efficiency.

An Interesting Development in Gas-Engine Design (Iron and Coal Trades Review, Oct. 23, 1925, vol. 111, p. 639). Brief particulars are given of the National gas-engine in operation at the Rockingham by-product plant, Sheffield, working on coke-oven gas. It is of the single cylinder per crank type, with an output of 600 b.h.p., and is coupled direct to a G.E.C. 400 kilowatt, three-phase generator. Before being delivered to the engine the gas is passed through Newton-Chambers purifiers.

C. Z. Rosecrans and G. T. Felbeck, *A Thermodynamic Analysis of Gas-Engine Tests* (Illinois University, Engineering Experiment Station, 1925, Bulletin No. 150).

VI.—*COAL WASHING AND HANDLING.*

Coal Handling.—P. Calfas, *The Hydraulic Unloading of Coal* (Génie Civil, Mar. 27, 1926, vol. 88, pp. 289–292). At the Saint-Ouen generating station of the Compagnie Parisienne de Distribution d'Electricité the loaded coal trucks are run alongside the coal store on a track which is tilted slightly to one side. A bridge crane spans the whole, and is fitted with an electric pump; water is raised from the bottom of the coal store, which is below ground level, and is forcibly directed on the coal in the trucks, so sluicing it out of the side discharge doors into the coal store, where the water and coal separate out again.

Coal Screening.—R. H. Kirkup, *The Screening of Coal* (Paper read before the Manchester Geological and Mining Society, Dec. 8, 1925: Iron and Coal Trades Review, Dec. 18, 1925, vol. 111, p. 1000). The author deals with the problems involved in the screening of coal, and describes the TK rotary screen.

Coal Washing.—W. R. Chapman and R. A. Mott, *The Cleaning of Coal* (Fuel, Apr. 1926, vol. 5, pp. 143–149). The nature of the inorganic material in coal and of other impurities is considered, and the means for their elimination are discussed. The great advantages in improving the heat value of coal and reducing its bulk are pointed out.

A. Andry, *The Fundamental Bases of the Rheolaveurs, the Improvements of the Plants, and some Results of Actual Washing* (Proceedings of the South Wales Institute of Engineers, 1926, vol. 41, pp. 567–590). The author reviews the developments of the Rheolaveur coal-washing process, and gives a number of actual results of practical washing with rheolaveurs.

A. Andry and G. B. Robinson, *The Rheolaveur Process of Washing Coal* (Colliery Guardian, 1925, vol. 130, Dec. 18, pp. 1427–1460; Dec. 24, pp. 1521–1522). The washing of coal by the Rheolaveur process is described and illustrated.

E. L. Warburton, *Wet Washing of Coal at Corbin, British Columbia* (Transactions of the Canadian Institute of Mining and Metallurgy, 1924, vol. 27, pp. 524–532). The problems involved in cleaning coal from the Corbin mines are considered, and particulars are given of the washing plant in operation.

H. Thompson, *A New Coal Washery in Northumberland* (Colliery Engineering, Apr. 1926, vol. 3, pp. 168–171). An illustrated description is given of the Baum single-tank coal washer in operation at the plant of the East Holywell Coal Co., Ltd.

Coal Washing on Concentrator Tables (Iron and Coal Trades Review, Jan. 8, 1926, vol. 112, pp. 51–54). A detailed description, with illustrations, is given of the washing plant on the concentrator system, in operation at the Weetslade Colliery, Burradon. The plant, which is the first of its kind in the United Kingdom, is arranged for washing coal from $\frac{7}{8}$ inch to 0 inch. There are four concentrating tables of standard design.

Spiral Cleaning Plant and Remodelling of Surface Plant at Seaham Colliery (Iron and Coal Trades Review, Jan. 15, 1926, vol. 112, pp. 91–93). An illustrated description is given of the plant in operation at this colliery, where coals are cleaned to very fine limits by spiral separation.

T. M. Chance, *The Mt. Union Sand-Flotation Plant for Preparing Bituminous Coal* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). Particulars are given of the design and operating results of the coal-cleaning plant at Mt. Union, Pennsylvania. This is the first plant to use the sand-flotation process in America.

T. Fraser and H. F. Yancey, *The Air-Sand Process of Cleaning Coal* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). "Air-sand" is the term which has been given to a process of separating refuse from coal by means of a body of dry sand artificially fluidised, and maintained in that condition by a continuous stream of air bubbles flowing through the sand body. By proper regulation of the rate of air flow, this fluid air-sand body may be maintained at such a density that coal will float near the surface and the refuse sink to the bottom. Methods of producing and characteristics of the air-sand medium, and the results obtained by the method, are given.

C. H. S. Tupholme, *Cleaning Coal by the Sand-Flotation Process* (Colliery Engineering, Apr. 1926, vol. 3, pp. 149–152). The principle of the sand-flotation process is explained.

Maclaren, *The Application of X-Rays to the Determination of the Washing Characteristics of Coals, and to the Control of the Washing*

Operations (Paper read before the Société de l'Industrie Minérale, Jan. 31, 1925: Revue de l'Industrie Minérale, Comptes Rendus, Jan. 1, 1926, No. 121, Part 2, pp. 1–12).

J. Roberts, *The Drying of Coal* (Colliery Engineering, Mar. 1926, vol. 3, pp. 110–112). The drying of coal is discussed, with special reference to the Carpenter centrifuge.

K. N. Moss, *The New Coal Treatment Laboratory at Birmingham University* (Paper read before the South Staffordshire and Warwickshire Institute of Mining Engineers, Dec. 14, 1925: Transactions of the Institution of Mining Engineers, 1926, vol. 70, pp. 178–195; Iron and Coal Trades Review, Dec. 18, 1925, vol. 111, pp. 1011). The author briefly reviews the coal-treatment processes, and describes the plant installed or to be installed at Birmingham University. This includes Baum and Draper washers, a pulverised fuel plant, and a briquetting plant.

Coal Storage.—C. H. S. Tupholme, *Coal Storage for Power Plants* (World Power, Feb. 1926, vol. 5, pp. 90–92).

R. B. Williams, *Store Your Coal Now* (Blast-Furnace and Steel Plant, Sept. 1925, vol. 13, pp. 361–363). Some practical notes and suggestions on the storage of large and small stocks of bituminous coal.

J. E. Lea, *Measurement of Coal* (Paper read before the Institution of Civil Engineers (Manchester and District Association) on Dec. 16, 1925: Gas Journal, Jan. 6, 1926, vol. 173, p. 30). Proofs are put forward that equal volumes of coals means equal weights, and it is suggested that the weighing of coals may be replaced in many instances by measuring its volume.

Spontaneous Heating of Coal.—J. D. Davis and J. F. Byrne, *Influence of Moisture on the Spontaneous Heating of Coal* (Industrial and Engineering Chemistry, Mar. 1926, vol. 18, pp. 233–236). Certain coals were treated in an adiabatic calorimeter with oxygen, both wet and dry, in the condition as received and after varying degrees of drying. The results of the experiments showed that coal in the condition as received will not heat in dry oxygen. If the oxygen be saturated at room temperature the coal will heat up or cool down, depending on the rate of evaporation of the moisture, which is dependent on the rate of circulation of the oxygen; in fact, even at 70° C. the heat abstracted as latent heat of evaporation may exceed the heat of oxidation. The spontaneous heating of thoroughly dried coal is very slow about that temperature, and tends to cease in the neighbourhood of 97° C., indicating that some moisture is essential to the spontaneous heating reactions.

Briquetting of Coal.—*Briquetting, with Special Reference to the Thornley Binder* (Colliery Guardian, Oct. 23, 1925, vol. 130, p. 939). Brief particulars are given of the Thornley binder for coal briquettes,

in which the active constituent is derived from sea-weed. It is claimed that the binder possesses a number of advantages over pitch. The weed is converted into pulp and then mixed with about 50 per cent. of its bulk with bitumen under pressure in autoclaves. Here a stable emulsion is formed which is run out and allowed to cool. This sets in a solid mass and is broken up for transport. The binder is used in the same manner as pitch, and no alteration of briquetting plant is necessary. The cohesion value is 80 to 95 per cent. as compared with 60 to 75 per cent. on pitch briquettes.

C. H. S. Tupholme, *The Manufacture of Briquettes* (Colliery Engineering, Mar. 1926, vol. 3, pp. 131–133). Coal briquetting practice and the design of briquetting plant are briefly discussed.

F. W. Foos, *The Briquetting of Brown-Coal* (Braunkohle, 1925, vol. 24, pp. 753–756). A brief discussion of the methods in use.

PRODUCTION OF IRON.

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I.—*MANUFACTURE OF PIG IRON.*

Blast-Furnace Construction.—A. G. McKee, *Some Observations regarding Blast-Furnace Design* (Proceedings of the Engineers' Society of Western Pennsylvania, Jan. 1926, vol. 41, pp. 391–411). A review of the development of the blast-furnace and an examination of the modern trend in their improvement.

R. Spannbauer, *Influence of Blast-Furnace Top Design on the Distribution and Descent of the Burden* (Stahl und Eisen, Jan. 7, 1926, vol. 46, pp. 8–11). The manner in which the materials charged into a blast-furnace will distribute themselves is well known to depend upon the design of the bell, and illustrations of various types of blast-furnace tops, including the Parry cup and cone and Langen's bell, show the effect of different designs on the distribution within the furnace. The influence of size of material is, however, a very important factor. The coke and ore, if not of uniform size, should be graded into their different sizes before charging. The bell should be so designed that the larger lumps gravitate to the centre, and the finer material towards the wall in gradually diminishing size. The Parry cone is the most effective apparatus for producing this formation. The top of the bosh should not be more than 3·6 metres above the tuyeres, even in the largest blast-furnaces, and the bosh angle should not be less than 76°. American experience fixes the limits as 3 metres for the height of the bosh and 80° for the angle.

New Stack Rated at 700 Tons (Iron Trade Review, Dec. 3, 1925, vol. 77, pp. 1401–1403, 1440). The outstanding features in the design of the new blast-furnace and auxiliary equipment at the plant of the Youngstown Sheet and Tube Co., Indiana, are described and illustrated.

Tonawanda Furnace Modernised (Iron Age, Jan. 28, 1926, vol. 117, pp. 269–271). The Tonawanda blast-furnaces at North Tonawanda, New York, which have been acquired by the American Radiator Co., originally consisted of two stacks. One of these stacks has been

abandoned and the other has been entirely remodelled. Particulars of the alterations carried out are given.

Drying Blast-Furnace Linings (Iron and Coal Trades Review, Dec. 18, 1925, vol. 111, p. 1009). The system of drying blast-furnace linings usually adopted when hot-blast is not available is to build a fire inside the hearth. The air has then to be admitted through the tapping hole and slag notch, with the result that a large proportion of air is drawn up the shaft without passing through the fire, resulting in poor combustion and temperature low and insufficient to properly dry the lining. At a blast-furnace plant on the North-East Coast an auxiliary furnace or oven is built immediately outside the slag notch. A plate is provided to cover the fire-hole and as much of the ash-pit as desired. The furnace was first fired with coal, but good results are obtained with less fuel, using rough coke. The temperature is completely under control, and can be increased by raising the bleeder and the plate in front of the ash-pit door. Excellent results have been obtained by this method, and it has been found in practice that there has been a reduction of 50 per cent. in the fuel consumed per day.

Trumbull Steel Breaks another Record (Blast-Furnace and Steel Plant, Sept. 1925, vol. 13, pp. 353–356). In 1924 the Trumbull Cliffs blast-furnace, with a bosh diameter of 20 feet 6 inches, set up a world's record by producing 25,000 tons of iron during October; one single day's tap exceeded 1000 tons. This was made possible by most vigorous control of all raw materials, pressures of blast, &c. The same idea has been applied to the 100-ton open-hearth furnaces. The first run recorded a gross tonnage of 30,000 tons of steel through No. 6 furnace. It was then completely repaired in four days and the second run started; at the time of writing over 35,000 tons of steel had been tapped out, and it appeared likely that the furnace would still serve up to 40,000 tons. The average time of heats was about nine hours ten minutes, with weekly runs of fourteen heats. The fuel was straight coke-oven gas, without admixture of tar or oil.

E. C. Kreutzberg, *Stack Smelts Foreign Iron Ores* (Iron Trade Review, Mar. 18, 1926, vol. 78, pp. 703–706). An illustrated description of the blast-furnace plant of the Delaware River Steel Co., Chester, Pa.

Cuts Blast-Furnace Costs (Iron Age, Mar. 18, 1926, vol. 117, pp. 769–771). Particulars are given of the alterations made to the blast-furnace of the Delaware River Steel Co., Chester, Pa. The furnace has been fitted with a new skip hoist, a McKee revolving top, and Morrison electric bell hoists. An ore dock equipped with modern unloading appliances and a new storage bin system have also been added to the plant.

Blast-Furnace Practice.—*Rating the Capacity of a Blast-Furnace* (Iron Age, Jan. 28, 1926, vol. 117, p. 283). A rule has been adopted by the Southern Ohio Pig Iron and Coke Association for determining

the capacities of blast-furnaces. This is based on the assumption that a blast-furnace lining has a life of four years, and that a sixty-day period would be required for renewal and general repairs. It is concluded that the annual capacity of each stack should be calculated by multiplying the daily rated capacity by 350 operating days. A formula for determining the daily rated capacity was set up by the Association in October 1920 for each grade of pig iron. It states that a furnace should burn 60 lbs. of coke per cubic foot of working volume each twenty-four hours, and that the working volume is to be measured as the volume from the centre line of tuyeres to a point 2 feet below the bell when closed. The coke should have 89 per cent. fixed carbon, less than 1 per cent. sulphur, between 9 and 10 per cent. ash, and between 1 and 2 per cent. volatile matter. The factors affecting the annual capacity of a blast-furnace are discussed in a paper read before the Association by H. A. Berg. Tabulation of figures representing sixty American blast-furnaces gives an average of 707,000 tons for a furnace lining.

J. S. Fulton, *A Method of Determining Comparable Blowing Practices for Iron Blast-Furnaces* (Proceedings of the Engineers' Society of Western Pennsylvania, Jan. 1926, vol. 41, pp. 460–475). The difficulties encountered in attempting to measure the amount of free air actually blown into a blast-furnace are enumerated. It is shown how an analysis of the monthly report of a furnace can be utilised to provide this information. A real comparison of blowing practices can then be made.

M. Derclaye, *Evaluation of the Characteristics of a Blast-Furnace as Functions of the Quantity of Slag Produced* (Revue Universelle des Mines, Dec. 1, 1925, vol. 8, pp. 270–285). The author calculates the amount of heat generated within the furnace, the coke consumption, the efficiency of the fusion zone, the ratio of CO_2 to CO, the speed of the passage of the charge through the furnace, and the weight of air necessary per kilogramme of metal, in terms of the known weight of slag produced. He also gives a second formula for calculating the coke consumption from the temperature of the hot-blast, the efficiency of the fusion zone, the carbon content of the coke, and Grüner's index.

M. Derclaye, *Complete Thermal Balance of a Typical Furnace Smelting Briey Minette Ore for the Basic Bessemer Process and Furnished with Cowper Stoves, and Utilising all the Available Energy of the Gases in Internal Combustion Engines* (Revue de Métallurgie, Mémoires, Jan. 1926, vol. 23, pp. 1–7). The metallurgical efficiency of the furnace was 46·48 per cent., and, considered as a producer of motive power, 8·93 per cent., giving a total over-all efficiency of 55·41 per cent.

T. L. Joseph, P. H. Royster, and S. P. Kinney, *Effect of the Physical Properties of Ore and Coke on the Capacity of the Blast-Furnace* (Proceedings of the Engineers' Society of Western Pennsylvania, Jan. 1926, vol. 41, pp. 428–459). An account of investigations carried out by the United States Bureau of Mines. It is shown that the size of the coke has a greater effect than its combustibility on the length or shape of

the combustion zone. Where the coke is charged by volume, changes in its density may have an effect on the rate of driving which is sometimes incorrectly attributed to other causes. The rate of gasification of carbon at the tuyeres regulates the flow of stock in the shaft. The rate of reduction is a function of the size of the ore particles. It is suggested that the capacity of a furnace may be increased by changes which will give better contact between the gases and the solids.

S. P. Kinney, *Relation of Carbon Consumption to Material Smelted in the Blast-Furnace* (Blast-Furnace and Steel Plant, Jan. 1926, vol. 14, pp. 15, 24). The data presented was compiled from the records of a 300-ton furnace in the Southern District (U.S.A.). For a period it was found necessary to operate with a high-ash coke, and the opportunity was taken to note the effect of this change in the composition of the coke. As the ash in the coke increased the production of iron decreased, but the weight (pounds) of material smelted per pound of carbon remained practically constant.

P. Geimer, *Necessity of Measurements in Blast-Furnace Practice and Working* (Stahl und Eisen, Feb. 11, 1926, vol. 46, pp. 173–179). By means of a few practical examples it is shown that the regular recording of certain data in blast-furnace working is both useful and necessary. In particular, the continuous recording of the composition of the waste gases gives important indications of the working of the furnace. Instruments for measuring the temperature of the gases and the level of the burden should always be installed and used regularly.

K. Hofmann, *The Developments in Pig Iron Production within the Last Decade with Respect to the Technical and Chemical-Metallurgical Points of View* (Zeitschrift für Angewandte Chemie, 1925, vol. 38, pp. 1058–1064, 1085–1088). The author reviews theoretical and practical developments in blast-furnace operations. The various reactions which take place are described. Recent developments in the construction and working of electric furnaces are also dealt with.

K. Hofmann, *The Mechanism of the Reduction of Oxides of Iron in Gas Currents* (Zeitschrift für Angewandte Chemie, 1925, vol. 38, pp. 715–721 ; Stahl und Eisen, Nov. 5, 1925, vol. 45, p. 1857). In experiments to examine the decomposition of the higher oxides of iron in a current of hydrogen gas, the author used ferric oxide and magnetic oxide powder from various sources in the pure state and also mixed with gangues of various kinds; the fineness of the material was varied, and the experiments were extended over the temperature range 500° to 1000° C. He concludes that the blast-furnace equilibrium diagram bears no direct relationship to the process actually occurring in the blast-furnace, because it takes no account of the velocity of the reactions, nor of their mechanism. The composition of the gas at all horizontal planes in the blast-furnace is such that it would tend to produce metallic iron corresponding to the diagram, if the reaction were high enough and there were no check owing to "passive resistance." To understand fully the mechanism of reduction in the blast-furnace the working of

these passive resistances and also the effects due to the free surfaces of the ores must be studied. The author records other interesting results of his work.

K. Hofmann, *The Dissociation Equilibrium of Steam and Carbon Dioxide in a Heterogeneous System with Iron and its Oxides* (Zeitschrift für Electrochemie, 1925, vol. 31, p. 172; Stahl und Eisen, Oct. 15, 1925, vol. 45, p. 1751). By means of the known figures for the equilibrium of CO_2 in the presence of Fe_3O_4–FeO and of FeO–Fe, and the equilibrium of the homogeneous system steam-carbon dioxide, the author calculates the equilibria of steam and carbon dioxide in heterogeneous systems with Fe_3O_4–FeO and with FeO–Fe. His figures check the earlier results of Wöhler and Günther, and of Schreiner and Grimmnes. He draws the conclusion, however, that, from the point of view of the phase rule, the results of the carbon dioxide heterogeneous equilibrium are of doubtful applicability to blast-furnace reactions, because in these there is present one phase too many for equilibrium, owing to the presence of free carbon or coke according to whether a temperature above or below the triple point (564° C.) is in question.

K. Hofmann, *Means for the Promotion of Indirect Reduction in the Blast-Furnace* (Stahl und Eisen, Oct. 8, 1925, vol. 45, pp. 1709-1711). The causes tending to prevent indirect reduction are chiefly slagging, and the sintering of the charge which delays the diffusion of the gases throughout the burden. The use of fine ore promotes indirect reduction, but a higher blast pressure is necessary to prevent scaffolding.

J. C. Surtees and C. S. Graham, *Economical Production of Pig Iron Suitable for Converting into Steel in the Open-Hearth Basic Furnace, having regard Specially to the Proportion of Local Stone used in the Burden of the Blast-Furnace* (Proceedings of the Lincolnshire Iron and Steel Institute, 1918–1920, vol. 1, pp. 106–120). The subject is discussed, with special reference to Lincolnshire practice.

E. Bormann, *The Effect of the Addition of Scrap to the Blast-Furnace Charge on the Working of the Furnace and on the Economical Production of Pig Iron* (Stahl und Eisen, 1925, vol. 45; Dec. 10, pp. 2041–2049; Dec. 17, pp. 2085–2091). The addition of large quantities of scrap to the blast-furnace charge causes changes in the working of the furnace; the temperature of the shaft and throat rises, the indirect reduction becomes less, and the carbon monoxide content of the waste gases increases. From the point of view of economy the procedure may, on the whole, be regarded favourably. A saving of coke of about 30 per cent. is possible, and production increases by about 60 per cent. This latter is an important point in the production costs of the pig iron, because the total charges per unit of pig produced are reduced. In addition, the greater heating value of the waste gases yields more power for driving other machinery. Among the disadvantages of the process may be mentioned the difficulties of charging and conveying the scrap, especially when light and loosely packed; the high losses and increased amount of cooling-water needed on account of the higher

shaft and throat temperatures; variations in the composition of the pig iron on account of non-uniformity of the scrap, and a lower carbon content in the pig iron. As regards the latter point, however, the difference between pig iron produced entirely from ore and that produced from a mixture of ore and scrap is very small. The disadvantages are far outweighed by the advantages enumerated above.

E. Bormann, *Scrap in Blast-Furnace Burdens* (Iron Age, Feb. 18, 1926, vol. 117, pp. 481–482). An English abstract of the above paper appearing in Stahl und Eisen.

H. H. Hopkins, *Bad Castings and Furnace Scrap* (Iron Age, Nov. 5, 1925, vol. 116, pp. 1252–1253). The use of scrap in the blast-furnace and its effect on the production of sound castings are briefly discussed.

R. Franchot, *Economic Significance of Cyanid Accumulation in the Blast-Furnace* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). From an efficiency viewpoint, the greatest loss of energy to the blast-furnace is in its failure to convert more than about a third of the coke carbon from carbon monoxide to carbon dioxide. This result has usually been ascribed to a necessity of a 2 : 1 excess of CO in order to reduce the iron. It has, however, been shown by other investigators that iron is completely reduced by equal volumes of carbon monoxide and carbon dioxide. The author is of the opinion that vaporisation, as cyanide, of accumulated alkalis is a serious primary factor, limiting the ratio of ore to coke. Observed cyanide vapour concentrations and those measured by the variations of the nitrogen-oxygen ratio in the hearth gases form the basis for a quantitative explanation of the furnace action.

E. B. Speer, *Tapping the Furnace in Safety* (Blast-Furnace and Steel Plant, Dec. 1925, vol. 13, pp. 478–481). The usual method of tapping a blast-furnace serves to weaken the notch by enlarging the orifice, but with the use of mechanical tapping machines, with their accuracy of adjustment, the notch can be drilled out without damage to the wall. Another very important point is that they are controlled by one man from a distance, thus eliminating the danger to the tapping crew that was ever present under old conditions.

E. E. Thum, *Opening Frozen Blast-Furnace Holes* (Iron Age, Nov. 5, 1926, vol. 116, pp. 1244–1247). The application of the oxygen lance for opening up tap holes, cinder notches, and flooded tuyeres is described and illustrated.

E. E. Thum, *Cutting Salamanders and Heavy Masses of Iron with an Oxygen Lance* (Blast-Furnace and Steel Plant, Jan. 1926, vol. 14, pp. 18–20). Methods are outlined whereby large masses of iron or steel may be reduced to sizes suitable for handling. The oxygen lance process is shown to be cheaper than the use of a rock drill, and also quicker.

Accident to Woodward Blast-Furnace (Iron Age, Apr. 8, 1926, vol. 117, pp. 987–988). Particulars are given of an accident which occurred at the No. 2 blast-furnace of the Woodward Iron Co., Woodward, Alabama,

resulting in the loss of twenty-one lives. The furnace was being blown out when, following a slip, the furnace shell was completely blown off at a point just above the mantle. The gas and blast mains were undisturbed. With the upper part of the furnace removed, the remaining stock was blown out by the blast and deposited over a radius of 75 feet. In its fall the shell crushed and buckled the skipway.

H. E. McDonnell, *Blast-Furnace Progress in* 1925 (Blast-Furnace and Steel Plant, Jan. 1926, vol. 14, pp. 16–17).

G. Godin, *Thermal Control in Ironworks* (Revue Universelle des Mines, 1926, vol. 9; Mar. 1, pp. 237–248; Mar. 15, pp. 266–278). The author demonstrates the calculation of a heat balance. By means of this it is possible to detect sources of loss of energies, and so render the working of the plant more economical.

Mixers.—E. Lepetre, *Pig-Mixers* (Revue de Métallurgie, Mémoires, Feb. 1926, vol. 23, pp. 82–91). The author has studied the form, size, construction, and working of pig-mixers. He finds that the cylindrical form is generally adopted, with electric control supplemented by hydraulic gear in case of need, and heated by gas and preheated air. Some desulphurisation occurs in the mixer, but the amount varies; it may rise as high as 40 to 45 per cent. of the sulphur in the pig metal as it comes from the blast-furnace. The dimensions of the mixer should be carefully worked out; best results are obtained when the mixer is of a sufficient capacity to hold the pig iron produced by the blast-furnaces in fourteen or fifteen hours. The author advocates careful study of the heat insulation of the mixer, and the taking of precautions to reduce the heat losses of the molten metal during transport to a minimum. On arrival at the steelworks the metal should never be cooler than 1280° to 1300° C.

Blast-Furnace Equipment.—G. Catella, *Modern Blast-Furnace Charging Apparatus* (Arts et Métiers, Oct. 1925, vol. 78, pp. 428–431). A description is given of blast-furnace charging equipment built by the Brown Hoisting Machinery Co.

M. Steffes, *Trials Run with the "Halberg-Beth" Type of Dry Purifier Installed at the Audun-le-Tiche Works of the Société Minière des Terres-Rouges* (Revue de Métallurgie, Mémoires, Jan. 1926, vol. 23, pp. 8–26). The company were using only about one-half of the blast-furnace gases derived from their works at Audun-le-Tiche. The problem of the utilisation of the remainder was solved by installing purifiers and supplying the gas through a conduit 5½ kilometres long to a factory at Esch-sur-Alzette. It was decided to use a dry method of cleaning the gases, and the trials described in the paper were run to test the efficiency and economical working of the gas-cleaning plant. The installation was found to be completely satisfactory, and it performed easily more than the minimum guaranteed.

New Blast-Furnace Blower (Iron Age, Mar. 11, 1926, vol. 117,

p. 690). Brief particulars are given of a new blast-furnace blower developed by the General Electric Co. It is made in three sizes, with capacities from 45,000 to 75,000 cubic feet, and each unit consists of a blower and driving turbine. The turbine is of the multi-stage type. Control is by a constant volume governor.

A. E. Maccoun, *Modern Blast-Furnace Stoves* (Proceedings of the Engineers' Society of Western Pennsylvania, Jan. 1926, vol. 14, pp. 412–427). A brief summary of modern blast-furnace stove development.

M. Zillgen, *Trials in the Use of Large Lining-Lumps in Stoves* (Stahl und Eisen, 1926, vol. 46, pp. 321–325). At the Buderus Ironworks at Wetzlar trials have been made in the use of large blocks for the walls of blast-furnace stoves. The dimensions were 180 × 180 millimetres, and the requirements for the best class of blocks were an alumina content of 40 to 42 per cent. and a refractoriness equal to cone 34. The efficiency of the stoves was found to be considerably improved, and the blast temperature could be more evenly controlled.

F. J. Crolius, *Dependable Gas Valves* (Blast-Furnace and Steel Plant, Apr. 1926, vol. 14, pp. 169–171). A description of a new type of spectacle valve for use in the gas mains of blast-furnaces. It is the invention of W. C. McGee, and is characterised by the fact that while it shuts perfectly gas-tight it opens quite easily. Thermal expansion of a metal tube is employed to allow of the easy movement of the valve plate.

R. Jones, *Metal Patterns for Iron Pig Moulds* (American Machinist (European Edition), Oct. 3, 1925, vol. 62, p. 72E). A detailed description of the method of making sheet metal patterns for pig moulds, as used for preparing casting beds to receive the metal from blast-furnaces. Whereas the ordinary patterns of birch, sycamore, or other hard wood are expensive to make and shortlived in use, due to shrinking and perishing, these metal patterns are very satisfactory, being cheap to make and durable in practice.

G. R. Walshaw, *Internal Traffic and Methods of Transport in Iron and Steelworks* (Proceedings of the Lincolnshire Iron and Steel Institute, 1918–1920, vol. 1, pp. 127–133).

Manufacture of Ferro-Alloys.—*New Stack for Ferro-Phosphorus* (Iron Age, Dec. 14, 1925, vol. 116, pp. 1731–1732; Iron Trade Review, Dec. 24, 1925, vol. 77, pp. 1595–1596). Illustrated particulars are given of the recently erected blast-furnace for the manufacture of ferro-phosphorus at Rockdale, Tennessee. It is the only blast-furnace producing this alloy in the United States. The stack is 70 feet in height with 12 feet hearth and 16 feet bosh. Because of the necessity of preventing any escape of phosphorus during the smelting process, the lower portion of the furnace is of special construction and differs from ordinary blast-furnace design. The furnace top includes a McKee revolving distributor.

N. Czako, *The Ferro-Alloy Industry* (Giesserei Zeitung, Feb. 15, 1926, vol. 23, pp. 89–94). The manufacture of ferro-alloys, the components of the principal alloys, their use in the metallurgical industries, and their effect on the product are discussed.

V. L. Eardley-Wilmot, *Molybdenum* (Canada, Department of Mines, Mines Branch, 1925, Report No. 592, pp. 162–164). During the period 1916–1918 two Ontario firms, the Tivani Electric Steel Co., Belleville, and the International Molybdenum Company, Orillia, undertook the manufacture of ferro-molybdenum and molybdenum salts. Brief particulars are given of the types of electric furnaces employed and various charges used.

Iron Industries of Various Countries.—H. Kreutz von Scheele, *Production of Electric Pig Iron in Finland* (Stahl und Eisen, Dec. 3, 1925, vol. 45, p. 2013). In 1920 an installation consisting of three single-phase furnaces of 450 kilowatts each was put in operation at Hämekoski, near the waterfalls of Jänisjoki, north of Lake Ladoga. The furnaces are of the low circular open type, with an electrode suspended from above, and with contacts in the bottom. The plant produces about 5000 tons of pig iron yearly of the following average composition: carbon, 3·5; silicon, 2·5; manganese, 0·8; phosphorus, 0·2; and sulphur, 0·02 per cent. The power consumption is 1600 kilowatt-hours, and about 340 kilogrammes of charcoal is consumed per ton of pig iron produced.

J. R. Cahill, *Report on the Economic and Industrial Conditions in France* (Department of Overseas Trade, London, 1925). This report, revised to July 1925, contains a review of the economic and industrial conditions in the French iron and steel and allied industries, and includes particulars of the dimensions and of the concentration developments of the principal French concerns.

The Coal Mining and Iron Industries of Upper Silesia after the Division (Glückauf, 1925, vol. 61; Oct. 17, pp. 1329–1338; Oct. 24, pp. 1365–1372; Oct. 31, pp. 1402–1406). The position of the coal and iron industries of Upper Silesia before 1914, and in the post-war years up to July 1925, is reviewed, and statistics of output are given, the figures being presented so as to enable a comparison to be made of the conditions in that part of territory allotted to Poland with those prevailing before the division took place. The production of German Upper Silesia is well maintained, the steel production being higher than before the war, and the coal production about equal. On the other side of the frontier the industries show a heavy decline, about 25 per cent. for coal, over 50 per cent. for pig iron, and 30 per cent. for steel. A useful map, showing the new frontier, marking the position of the mines, works, and towns on either side, is given.

J. H. Ledeboer, *The Blast-Furnace Works at Ymuiden* (Stahl und Eisen, Dec. 24, 1925, vol. 45, pp. 2105–2112). The new blast-furnace works of the Koninklijke Nederlansche Hoogovens en Staalfabricken is situated at the mouth of the North Sea Canal, which connects

Amsterdam with the sea, allowing of very convenient carriage of raw materials and distribution of products by water. The ore and coal stores are on the quay side ; to the west of this are arranged the bunkers, blast-furnaces, casting department, and power plant, while to the east are the coal and coke preparation equipment, the coke-ovens, and the by-product recovery plant. The blast-furnace is worked along American lines, and particular care is taken to keep the size of the coke regular. The whole of the works is very completely described and illustrated in the article.

R. Doderer, *History and Development of the Czecho-Slovakian Iron Industry* (Montanistische Rundschau, Jan. 16, 1926, vol. 18, pp. 44–47). A brief account is presented of the rise and development of the iron industry of Czecho-Slovakia. The history of the following principal undertakings is given : The Prager Eisen-Industrie Gesellschaft, which includes the Kladno works, the Teplitz rolling-mills, and the works of Königshof and Althütten ; the Witkowitz ironworks ; the Berg- und Hüttenwerks Gesellschaft, owning the Ostrau Karwin coal-mines, the majority of the shares of which were acquired by the Schneider group after the war ; and the Poldihütte, which manufactures special steels and tool steels. Other works include the Mannesmann Tube Works at Komotau.

J. Wagner, *The Metallurgy of Iron in Luxemburg before the Discovery of the Minette Deposits* (Revue de Métallurgie, Mémoires, Mar. 1926, vol. 23, pp. 121–125).

B. Kjerrman, *Some Comments on Swedish Steel Practice* (Transactions of the American Society for Steel Treating, Apr. 1926, vol. 9, pp. 585–596). The paper is a résumé of the methods of producing iron and steel in Sweden. A brief description is given of the distribution of ore deposits in Sweden, the fuels and furnaces used. An outline is given of the Walloon and Lancashire processes for wrought iron, and Bessemer, open-hearth, crucible, and electric furnace practice for the production of high quality Swedish steels.

R. Durrer, *Trials in the Smelting of Fricktal and Gonze Ores* (Stahl und Eisen, Mar. 11, 1926, vol. 46, pp. 328–332). Attempts have been made from time to time to exploit the ore-beds of Fricktal and Gonze in Switzerland. The article describes experiments made in small single-phase tilting furnaces with the object of ascertaining the best conditions for smelting these ores. The metallurgical operations are described in much detail, the composition of the ores and of other materials charged being stated. Coke breeze and charcoal were used as fuel, and a good quality of cast iron was obtained.

R. Mather, *Iron and Steel Manufacture in India* (Paper read before the Sheffield Society of Engineers and Metallurgists, Mar. 15, 1926 : Iron and Coal Trades Review, Mar. 26, 1926, vol. 112, pp. 530–531). A review is given of the rise and development of the iron and steel industry in India, including a survey of its raw material resources, statistics relating to it, and an estimate of the present position of pig

iron and steel manufacture in India, with an account of the plants engaged.

O. R. Kuhn, *Australia: The Infant in the Iron Industry* (Engineering and Mining Journal-Press, Dec. 12, 1925, vol. 120, pp. 931–938). A review of the history of the iron industry in Australia, and of its present state of development. The known reserves of iron are estimated at about 450 million tons as a minimum. Iron is found in all the states, including Tasmania and excepting Northern Territory, the latter being practically unexplored.

Bleibtreu, *American Blast-Furnace and Coke Industry* (Paper read before the Association of German Blast-Furnace Operators: Iron Age, Feb. 4, 1926, vol. 117, p. 346). An abstract is given of this paper, which describes the distinguishing characteristics of blast-furnace and coke-oven practice in the United States.

New Steel and Iron Capacity (Iron Age, Jan. 7, 1926, vol. 117, pp. 57–62, 101–104). Particulars are given of the additions made during 1925 to the blast-furnaces, open-hearth furnaces, electric furnaces, and rolling-mills in the United States. Ten open-hearth furnaces were built with an estimated capacity of 585,000 gross tons per annum, and fourteen were under construction. One blast-furnace was completed during the year and nine were under construction or projected. The estimated capacity of the nine furnaces is about 1,875,000 gross tons. Forty-three electric furnaces were installed.

S. B. Ely and W. F. Rittman, *Power and Fuel Consumption of the Iron and Steeel Industries of Pittsburgh* (Blast-Furnace and Steel Plant, Nov. 1925, vol. 13, pp. 449–455). An analysis of the present requirements and future potential power possibilities in the Pittsburgh district, with special reference to the iron and steel industries.

J. F. Froggett, *Quarter Century Inaugurates Age of Steel* (Iron Trade Review, Mar. 25, 1926, vol. 78, pp. 764–768, 792).

G. H. Manlove, *Revolutionary Changes are Made in Economics of Blast-Furnace Industry* (Iron Trade Review, Mar. 25, 1926, vol. 78, pp. 774–775, 793).

J. D. Knox, *Steelmakers Improve Practice* (Iron Trade Review, Mar. 25, 1926, vol. 78, pp. 776–777, 800).

D. M. Avey, *Quarter Century sees Marked Changes in Foundries* (Iron Trade Review, Mar. 25, 1926, vol. 78, pp. 782–784). The foregoing four articles survey the developments that have taken place in the American iron and steel industry during the past twenty-five years.

F. A. Foster, *Chinese Make Iron To-day as in the Dim Past* (Iron Trade Review, Mar. 25, 1926, vol. 78, pp. 801–804). An illustrated account of the native methods of mining and smelting iron ore in China.

J. W. Reichert, *The World Production of Iron and Steel* (Stahl und Eisen, 1926, vol. 46, pp. 65–73). A statistical summary is presented of the production of pig iron and steel in all countries from 1913 to 1925. The present total steel-making capacity of the world is put at 120 million tons, distributed as follows: United States 61 million tons,

Germany 16, United Kingdom 10, France and the Saar district 12, Belgium and Luxemburg 6, and all other countries 15 million tons.

Sir A. Balfour, *Effect of the World War on the Iron and Steel Business* (Transactions of the American Society for Steel Treating, Nov. 1925, vol. 8, pp. 621–634). The author deals briefly with the historical aspects of the iron and steel industry, and discusses the economic and financial factors of the industry both in Europe and America.

History of Iron.—R. Jenkins, *A Sketch of the Industrial History of the Coalbrookdale District* (Transactions of the Newcomen Society, 1923–1924, vol. 4, pp. 102–112). Interesting particulars are given of the important part played by the Coalbrookdale district in the development of the iron industry of Great Britain.

R. Jenkins, *Ironmaking in the Forest of Dean* (Paper read before the Newcomen Society, Nov. 18, 1925: Engineer, Nov. 27, 1925, vol. 140, pp. 575–577). The author narrates the history of ironmaking in the Forest of Dean from the earliest times up till 1890 when the Cinderford Works, the last remaining, closed down, marking the end of an industry which had been carried on continuously from a period probably earlier than the Roman occupation of Britain.

J. Henderson, *Notes on the Early History of the Ironmaking Industry of North Lincolnshire* (Proceedings of the Lincolnshire Iron and Steel Institute, 1918–1920, vol. 1, pp. 121–126).

Sir Robert Hadfield, *Early French Scientists and their Work* (Paper read before the French Congress of Chemical Industries, Paris, Oct. 1925: Engineer, Oct. 9, 1925, vol. 140, pp. 385–386). The author gives a list of twenty-six famous French savants of the eighteenth and nineteenth centuries, together with the treatises on which their fame is based. Very interesting information concerning these scientists and their work is recorded, and the personal details included in many cases give added fascination to the paper.

II.—*BLAST-FURNACE SLAGS.*

Utilisation of Slag.—K. Ellersiek, *Use of Slag in Industry* (Feuerungstechnik, 1925, vol. 13, pp. 245–248). In Germany slag from blast-furnaces and cupolas, used for building purposes, is often ground fine, mixed with water and powdered lime, pressed and hardened in steam under pressure, as in the sand-lime brick process. In a process recently developed, a sufficiently basic slag is used without lime, the pressed brick being exposed to gases containing carbon dioxide, such as blast-furnace gas.

III.—*PUDDLING.*

Manufacture of Wrought Iron.—J. Aston, *The Problem of Wrought Iron Manufacture, and a New Process for its Production* (Year-Book of the American Iron and Steel Institute, 1925, pp. 361–377). In the Aston process disintegration of iron is accomplished by pouring molten iron into a bath of slag. The fused slag acts as a chilling agent for the fused iron. When the iron is poured into the slag, there is almost instant solidification of the metal and a gas liberation of such force that the metal is comminuted into particles. The particles settle and collect at the bottom of the slag bath in a spongy, porous mass, similar to a well-puddled ball. The slag permeates all the interstices of the metallic mass. Excess slag may be poured or drained off and the mass shaped into a bloom in a squeezer or press. About three volumes of slag to one of metal will accomplish the desired end. The metal used in the process may be produced in Bessemer, open-hearth, or electric furnaces with usual charges and standard practice. The slag may be melted in any standard type furnace or cupola. An experimental plant has made about 850 heats, producing blooms about 800 lbs. in weight. The material produced has satisfied exacting specifications for high-grade wrought iron, and considerable amounts have been rolled to skelp or plate without repiling and then into pipe.

New Processes for Making Wrought Iron (Mechanical Engineering, Dec. 1925, vol. 47, pp. 1113–1114). The information contained in this article has been taken from papers presented at the meeting of the American Iron and Steel Institute at New York City on Oct. 23, 1925. The necessity for the introduction of mechanical manipulation in the puddling process in order to compete with steel is explained and several types of mechanical puddling furnaces are described. Another mechanical process is the invention of H. D. Hibbard, and this is also briefly described.

J. P. Roe, *The Roe Puddling Machine* (Year-Book of the American Iron and Steel Institute, 1925, pp. 348–360). The Roe puddling machine and auxiliary equipment are described and illustrated. The furnace is rectangular in shape and is supported on two hollow trunnions. The furnace can be oscillated through an angle of 120°. The door forms the whole of one end of the machine. The bottom as shown in longitudinal section is flat in the middle, which is tangential to the end portions, resulting in the extreme ends of the bottom being notably higher than the middle portion. An important feature of the process is the maintenance of a hot bottom, which is accomplished by not permitting the bath to cover more than one half, thus exposing the other half to the action of the flame. The whole period of making a heat averages sixty minutes. The weight of a charge is 1200 lbs., and five heats constitute a twelve-hour shift.

F. H. Dechant, *The Ely Process of Mechanical Puddling for the Production of Wrought Iron* (Year-Book of the American Iron and Steel Institute, 1925, pp. 337–347). A description is given of the Ely furnace, originally designed for the bushelling of scrap, but recently adapted to the puddling of iron. The furnace is of square section, the ends having ports for the entry of the heat and for the exit of the products of combustion. The furnace is mounted on two carrier rings, being supported by step blocks on the rings, so that the central axis through the ports coincides with the centre of the rings. The carrier rings permit the rotation and oscillation of the furnace. The furnace has been fired with fuel oil and pulverised fuel, and while gas has not been used it is believed that this type of fuel offers one of the best means of firing. The sequence of operations is the same as in the hand-puddling process. The chemistry of the process is discussed, and particulars are given of the auxiliary equipment to the furnace.

F. T. Sisco, *The Manufacture of Iron and Steel* (Transactions of the American Society for Steel Treating, Mar. 1926, vol. 9, pp. 458–470). The manufacture, properties and uses of wrought iron, malleable cast iron, and semi-steel are briefly dealt with.

S. J. Astbury, *The Wrought Iron Industry*, 1925 (Paper read before the Staffordshire Iron and Steel Institute: Iron and Coal Trades Review, Dec. 25, 1925, vol. 111, p. 1050).

H. E. Smith, *The Manufacture and Use of Wrought Iron* (Year-Book of the American Iron and Steel Institute, 1925, pp. 330-336). The author discusses the subject mainly from the point of view of a user. He refers to the numerous uses of wrought iron, and shows some of the difficulties which have been encountered in attempting to replace this material with soft steel. The relatively greater resistance of wrought iron to corrosion is touched upon. It is pointed out that the usual statement, that the wrought iron produced to-day is not so good as the product of years ago, is incorrect.

The Birth of the Puddling Industry (Foundry Trade Journal, Feb. 4, 1926, vol. 33, p. 99). Brief particulars are published of the part played by Joseph Hall in the introduction of the dry process of puddling.

FOUNDRY PRACTICE.

General Foundry Practice.—J. E. Hurst, *The Cupola Furnace* (Foundry Trade Journal, 1926, vol. 33; Mar. 4, pp. 170–172; Mar. 11, pp. 199–200). The combustion of coke, thermal balance sheet, cupola melting zone, composition of escaping gases, improved cupolas, factors in cupola design, tuyere area, number and shape of tuyeres, and the lining, are discussed.

E. Longden, *Comparisons in Foundry Methods and Processes* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Mar. 25, 1926, vol. 33, pp. 227–232). A discussion on cupola design and moulding practice.

T. Meierling and W. Denecke, *Desulphurisation of Cast Iron* (Giesserei Zeitung, Apr. 1, 1926, vol. 23, pp. 175–178). By blowing the metal very hot, desulphurisation takes place, when the charge has somewhat cooled, due to the segregation or freezing out of mixed crystals rich in manganese and iron sulphides. The effect is the same whether the metal is high in sulphur or has only a normal content. If the blowing is not vigorous no desulphurisation takes place in the above manner, as the metal is too viscous for the crystals to rise.

T. Klingenstein, *Desulphurisation in the Cupola Furnace, with Special Reference to the Use of Fluor-Spar* (Giesserei Zeitung, Oct. 15, 1925, vol. 22, pp. 621–631).

O. Weyer, *The Causes of Loss in the Cupola: The Amount of Blast, the Tuyere Area, and Weight of Charge* (Die Giesserei, 1926, vol. 13; Apr. 17, pp. 301–305; Apr. 24, pp. 317–322). A critical review of cupola practice, indicating the measures to be taken for the avoidance of losses in the cupola.

J. H. List, *Semi-Steel* (Foundry Trade Journal, Oct. 22, 1925, vol. 32, p. 343). The production of semi-steel in the cupola is briefly discussed.

Cupola Flames (Metal Industry, Oct. 16, 1925, vol. 27, pp. 367–368). It is pointed out that the average foundryman does not derive much information concerning the efficient working of the cupola from the ordinary analysis of the waste gases. The manner in which the foundryman may obtain this information by inspection of the flames above the charge and in the stack above the charging door is indicated.

R. A. Knight, *Judging the Coke Bed in the Cupola* (Foundry, Mar. 1, 1926, vol. 54, pp. 177–179).

Successful Cupola Practice (Metal Industry, Dec. 11, 1925, vol. 27, pp. 561–562). A brief description of the chief essentials for successful

cupola practice; the design of furnace is lightly touched on, and the actual manipulation is dealt with.

The Tuyere Problem (Metal Industry, Dec. 4, 1925, vol. 27, pp. 539–540). Within reasonable limits the shape of tuyeres is of less importance than other items of cupola practice. Where two rows of tuyeres are used, the upper ones perform a different function from the lower set, and should therefore not be of the same design. It is stated that the use of two rows of tuyeres offers no advantages.

Tuyere Arrangement (Metal Industry, Dec. 18, 1925, vol. 27, pp. 583–584). This article was written in answer to the foregoing. The use of two rows of tuyeres instead of one gave an increase of melting rate of about 30 per cent., and this without any ascertainable difference in the "melted-iron—total-coke" ratio. The carbon contents of the two irons produced under the two sets of conditions showed no appreciable difference, but the higher temperature obtainable with two rows of tuyeres was specially useful for short freezing range irons.

J. H. List, *Fluxing in Cupola Practice* (Foundry Trade Journal, Nov. 26, 1925, vol. 32, p. 459). The author outlines a method and presents formulæ for calculating the amount of limestone required for fluxing in cupola practice.

G. S. Evans, *Refine Iron with Alkali Flux* (Foundry, Mar. 1926, vol. 54, pp. 180–183, 187). The author gives details of the operation and some of the results obtained in using an alkali flux in melting foundry iron.

O. Lechner, *Practice in the Use of Foundry Mixtures with Briquetted Cast-Iron Turnings, and Rusted and Bright Steel Turnings* (Stahl und Eisen, Oct. 29, 1925, pp. 1802–1809). In consequence of irregularities in the strength and composition of cylinder metal for which mixtures containing large proportions of cast-iron briquettes were used, a number of trials were carried out to find the effect of adding increasing proportions of cast-iron briquettes, briquettes of rusted steel turnings, and briquettes of bright steel turnings. The weight of the briquettes was 10 kilogrammes each, and in charges of the total weight of 500 kilogrammes, briquettes were added in proportions increasing by 5 per cent. at a time up to 30 per cent. In general, with all three kinds of briquettes, the total carbon diminishes as the proportion of briquettes increases; the silicon also shows a marked decrease, the manganese a slight decrease, and the sulphur a very decided increase, especially when using briquettes of steel turnings. The complete results are all fully set out in tables and diagrams which show not only the compositions of the castings from the different mixtures, but their transverse and tensile strength as well.

H. P. Haertel, *Nomographs for the Calculation of Cupola Mixtures* (Die Giesserei, Apr. 10, 1926, vol. 13, pp. 287–290). A simple graphic method for calculating cupola mixtures is demonstrated.

B. Osann, *The Principles of Cupola Calculations* (Stahl und Eisen, Dec. 31, 1925, vol. 45, pp. 2147–2151). Calculations of the capacity of

the cupola, based on the rate of output, the diameter, height, quantity and pressure of the blast, blowing engines, &c., are presented.

R. Moldenke, *American Foundry Practice* (Proceedings of the Institute of British Foundrymen, 1923–24, vol. 17, pp. 227–243). A brief survey of certain aspects of foundry practice in the United States.

F. T. Sisco, *The Manufacture of Iron and Steel* (Transactions of the American Society for Steel Treating, Feb. 1926, vol. 9, pp. 305–322). A general account of the manufacture of iron and steel castings is given.

K. Hejcmana, *Power and Heat Problems in the Foundry* (Paper read before the Czecho-Slovakian Foundrymen's Association: Foundry Trade Journal, 1926, vol. 33, Apr. 8, pp. 269–271; Apr. 15, pp. 287–290). The author discusses the economic distribution of power and heat in foundries. Heat balances and distribution of heat losses in cupolas, electric furnaces, mould drying stoves, and open-hearth furnaces are shown diagrammatically.

D. Wilkinson, *Recurring Foundry Problems* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Mar. 4, 1926, vol. 33, pp. 165–169). A discussion of some of the problems encountered in the production of sound castings.

J. E. Fletcher, *Some Applications of Research to Modern Foundry Practice* (Paper read before the Institution of Mechanical Engineers: Foundry Trade Journal, Dec. 24, 1925, vol. 32, pp. 530–532; Jan. 14, 1926, vol. 33, pp. 31–33).

J. L. Francis, *Special Cast Irons. A Comparison of the Lanz-Perlit and the Thyssen-Emmel Processes* (Metal Industry, Jan. 22, 1926, vol. 28, pp. 85–87). The author puts forward evidence to show that the cast iron produced by the Thyssen-Emmel process is superior to that resulting from the Lanz-Perlit method. He suggests that the former procedure is more simple, and more certain in its results.

A. J. Richman, *The Production of Diesel Castings in Pearlitic Cast Iron* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1925, vol. 32, Nov. 26, pp. 449–451; Dec. 2, pp. 471–474). A discussion of some of the problems encountered in the production of pearlitic cast iron. Reference is made to the Lanz and Thyssen-Emmel processes for producing a pearlitic structure. The effect obtained by preheating the mould in the Lanz process can also be obtained by casting at a very high temperature into a warm mould to avoid sudden chilling. The pearlite formed can be of a coarsely laminated nature, or a fine unlaminated condition, depending on the silicon content and the rate of cooling. To obtain the unlaminated structure, an iron having a very low total carbon, silicon, and phosphorus content must be used. The total carbon should not exceed 3·2 per cent., and phosphorus not above 0·3 per cent. Castings for internal combustion engines are subjected to the following conditions: (1) High temperatures; (2) repeated impact; and (3) hard wear. The drawback with all ordinary pig irons is the high total carbon content, and to

counteract this and reduce the silicon, steel additions should be made in the mixture. When using steel in the cupola, low blast pressure with big volume is the best practice. A portion of the paper is devoted to a description of moulding practice for castings for Diesel engines.

H. J. Young, *Perlit Iron* (Lecture to the Institute of British Foundrymen: Foundry Trade Journal, Feb. 11, 1926, vol. 33, pp. 115–116).

J. E. Hurst, *Some Further Notes on Pearlitic Cast Iron* (Foundry Trade Journal, Feb. 4, 1926, vol. 33, pp. 95–97).

K. von Kerpely, *High Quality Cast Iron with High Carbon and Phosphorus as an Electric Furnace Product* (Stahl und Eisen, Dec. 3, 1925, vol. 45, pp. 2004–2008). It is shown that it is quite within the bounds of possibility to produce from a mixture of scrap high in phosphorus, carbon, and silicon, and with no addition of any pig iron whatever. a high quality cast iron of high tensile strength by superheating the metal to between 1500° and 1700° in the electric furnace. The influence of superheating to the correct degree on the mechanical properties is as important as that of chemical composition.

K. von Kerpely, *Practical Experience in the Manufacture of High Quality Cast Iron in the Electric Furnace According to the Duplex Process* (Giesserei Zeitung, Jan. 15, 1926, vol. 23, pp. 33–44). Practice in the production of high quality cast iron is described. The metal was first melted in the cupola and then finished in the electric furnace. The product owes its good properties, apart from the influence of the proportions of carbon, silicon, and phosphorus, to superheating in the electric furnace. In fact this latter point is the determining factor in conferring high tensile properties on the castings.

K. von Kerpely, *Cast Iron from Electric Furnaces* (Iron Age, Mar. 18, 1926, vol. 117, p. 760). An English abstract of a paper presented at a convention of German foundrymen in Berlin on Jan. 16, 1926. The author describes the production of high-grade cast iron from poor quality scrap by using a cupola and electric furnace in combination. The cast iron produced has a minimum tensile strength of 38,500 lbs. per square inch and a minimum bending strength of 55,000 lbs. per square inch. It is claimed that superheating the iron to 1500° to 1700° C. produces the high strength values.

E. Richards, *Melting Grey Cast Iron in the Electric Furnace* (Stahl und Eisen, Feb. 25, 1926, vol. 46, pp. 249–254). Owing to the increasing demand for castings low in phosphorus and sulphur, attention has been of late directed to the use of the basic-lined electric furnace for the further refinement of the metal after melting in the cupola. The cupola cannot be dispensed with, but it is possible by continuing refining operations in an electric furnace to reduce the phosphorus and sulphur to below 0·05 per cent. respectively. The metal can also be superheated, which is an advantage in pouring the castings and greater homogeneity can be secured. Practice in producing castings by this duplex method is described.

C. Gilles, *The Production of Cast Iron of High Tensile Strength*

(Giesserei Zeitung, Apr. 15, 1926, vol. 23, pp. 203–212). The production of pearlitic iron is discussed; the cupola is not to be depended upon alone for a satisfactory product, and the oil furnace or electric furnace is recommended as an auxiliary. Particular reference is made to the use of the Wüst furnace.

T. Klingenstein, *The Wüst Furnace for Refining Special Cast Iron* (Iron and Coal Trades Review, Jan. 8, 1926, vol. 112, pp. 60–61). Sectional drawings are given of the Wüst furnace, for the production of cast iron of uniformly low carbon content. In principle it is a reverberatory-cupola furnace, in which an oil burner is erected on one side while a charging shaft is erected on the other. The flame first sweeps the bath, strikes against the lower part of the charge column in the shaft and melts it down for running off into the hearth, while fresh material is charged down from above or delivered through the throat. The blast is preheated on the counter-current system, a blast temperature of 400° C. being obtained. As in the cupola furnace, the charge is delivered from the charging stage with a lime addition of 1 to 2 per cent., the sole difference being that no coke is necessary. Several examples are given of heats made in a 1-ton furnace. The temperature of the tapped iron is between 1500° and 1600°. The improvement in the quality of cast iron melted by this method consists, apart from the low sulphur content, in the finer graphite separation and in the possibility of obtaining with accuracy a uniformly low carbon content of the particular analysis desired. The graphite is separated more in the form of temper carbon, and not in the usual lamellar form.

T. Klingenstein, *High Quality Cast Iron* (Zeitschrift des Vereines Deutscher Ingenieure, Mar. 20, 1926, vol. 70, pp. 387–390). The author describes the production of pearlitic cast iron in the Wüst furnace.

T. Klingenstein, *The New Wüst Furnace for Refining Special Cast Iron* (Foundry Trade Journal, Dec. 10, 1925, vol. 32, pp. 487–490; Stahl und Eisen, Aug. 27, 1925, vol. 45, pp. 1476–1478). (Abstract in this Journal, 1925, No. II. p. 418.)

B. Osann, *Reverberatory Furnaces for Foundry Work* (Stahl und Eisen, Mar. 25, 1926, vol. 46, pp. 389–393). Various types of reverberatory furnaces for melting foundry iron are illustrated and described. Both gas-fired and oil-fired furnaces are shown. Some novel features especially as regards charging devices for dealing with heavy scrap are noted.

German Foundrymen's Association (Foundry Trade Journal, Feb. 11, 1926, vol. 33, pp. 111–113). A symposium was held in Berlin on Jan. 16, 1926, by the Verein deutscher Giessereifachleute on electric furnace practice. Abstracts are given of the following papers:

K. v. Kerpely, *The Production of High Grade Cast Iron in the Electric Furnace.*

G. Mars, *Electric Steel Melting.*

H. Nathusius, *The American Electric-Heating Furnace in the Iron and Steel Foundry.*

E. F. Rogers, *Mechanically Charging the Cupola* (Iron Age, Dec. 3, 1925, vol. 116, pp. 1514–1515). Brief illustrated particulars are given of the methods adopted at an American foundry for the charging of cupolas.

W. G. Hammerstrom, *Charges Cupolas Mechanically* (Foundry, Nov. 15, 1925, vol. 53, pp. 908–910). An illustrated description of an electric charging device in operation at an American foundry. The charger is operated by one man and replaces a crew of eight on the charging platform.

M. J. Cooper, *Standardisation in Modern Foundry Practice* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Feb. 18, 1926, vol. 33, pp. 129–132). The author puts forward a number of suggestions for the standardisation of foundry appliances such as rammers, moulding boxes, spindles for loam moulding, runner plugs, skimmers, runner bushes or cups, dressing tools, cupola equipment, and foundry cranes.

A. A. Wood, *Cutting down Waste on Castings* (Iron and Steel of Canada, Mar. 1926, vol. 9, pp. 98–99). The author suggests some ways in which the waste and losses experienced in foundry work may be reduced.

J. Longden, *Liquid Shrinkage in Grey Iron* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Feb. 4, 1926, vol. 33, pp. 85–92).

E. Bauer, *Contraction and Stress in Castings* (Giesserei Zeitung, 1926, vol. 23, Feb. 1, pp. 61–73; Feb. 15, pp. 95–102; Mar. 1, pp. 121–128). Calculation of shrinkage, the effect of shrinkage, and measures for the prevention of defects arising therefrom, are discussed.

H. Malzacher, *Some Results of Insufficient Allowance for Contraction in Steel Castings* (Giesserei Zeitung, Nov. 1, 1925, vol. 22, pp. 653–657), The effect of hindrances to contraction in steel castings is discussed and illustrated with the aid of a few practical examples.

Thomas, *New Methods in the Test Control of Castings* (Paper read before the Franco-Belgian Foundry Congress: Metal Industry, Nov. 6, 1925, vol. 27, pp. 439–440). Reference is made to tests on certain irons, as a result of which certain fairly definite relations were established between their various properties. These data have been used for the establishment of a simple yet rigorous control of the quality of the general production of the large French marine engineering foundry, l'Établissement de la Marine d'Indret.

Steel Foundry Practice.—F. A. Melmoth, *Some Metallurgical Points in Electric Steel Castings, and Notes on Defects* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Dec. 31, 1925, vol. 32, pp. 549–552). Electric mild steels can be produced either by the single or double slag process, the choice depending on the quality of the scrap material available, or the degree of purity demanded in the metal. The single slag method produces a material more capable

of running light sections, owing to the greater degree of fluidity. In the author's opinion the viscous nature of the charge sometimes encountered in the double slag method is probably connected with the strongly reducing conditions prevailing. The author discusses the effect of high temperature and high silicon combined, contraction of the metal, behaviour of the steel in the mould, and absorption of mould gases. The nature of the following defects met with in steel castings is also outlined: porosity, contraction cracks, contraction cavities or "draws," and blown castings.

G. Varley, *Manufacture of Steel Castings* (Transactions of the Liverpool Engineering Society, 1924, vol. 45, pp. 133–167). The general principles of melting practice for the production of steel castings are discussed. The moulding and heat treatment of steel castings are also briefly dealt with.

W. J. Corbett, *Steel Castings* (Year-Book of the American Iron and Steel Institute, 1925, pp. 166–188). A general discussion on the production and uses of steel castings, with special reference to American practice.

E. Blau, *Electric Furnaces in Foundry and Metallurgical Service* (Chemiker Zeitung, 1925, vol. 49, pp. 673–674, 698–701). An outline is given of the types of furnaces in use in the iron and steel industry.

J. Sonnenfeld, *Recounts Experience with Steel Melting Units* (Foundry, 1925, vol. 53, Dec. 1, pp. 964–965; Dec. 15, pp. 1009–1010). The author discusses converter and acid electric melting practice for the production of steel castings.

O. Held, *Small Converter Practice in the Steel Foundry* (Giesserei Zeitung, Dec. 1, 1925, vol. 22, pp. 717–722). A general review of steel melting practice in the small converter.

D. M. Avey, *Heats Steel Hotter* (Foundry, Feb. 1, 1926, vol. 54, pp. 88–91, 124; Iron Trade Review, Feb. 4, 1926, vol. 78, pp. 325–328). The first Bosshardt open-hearth furnace to be put into operation in America was installed in Nov. 1925 at the plant of the Wanner Malleable Castings Co., Hammond, Indiana. A detailed description of the furnace and the method of operation is given.

Recommended Practice for Steel Castings for Gears (American Machinist (European Edition), Nov. 29, 1925, vol. 63, p. 646). A brief account of the recommended practice for steel castings for gears, adopted by the American Gear Manufacturers' Association at a meeting held on Oct. 1–3, 1925. Suggestions are laid down concerning the process of manufacture of the steel, discards, heat treatment, chemical composition and analyses, as well as other matters.

R. W. Thomas, *Influence of Oxy-Acetylene Cutting on Steel Foundry Practice* (Paper read before the International Acetylene Association, Chicago, Nov. 1925). It is pointed out that the cost and time spent in removing gates and risers from castings is far less with the oxy-acetylene torch than with any other methods.

Structures Change with Alloy Additions in the Ladle (Foundry,

Nov. 15, 1925, vol. 53, pp. 927–928). The improvement in the physical structure of iron and steel castings by the addition of nickel and chromium is briefly dealt with.

Moulding Sands.—E. Diepschlag, *Constitution of Moulding Sands* (Die Giesserei, 1926, vol. 13, Feb. 13, pp. 125-130; Feb. 20, pp. 149–154; Feb. 27, pp. 173–176; Mar. 6, pp. 189–194; Mar. 13, pp. 209–213). The subject is dealt with under the following heads: methods of testing moulding sands and results of tests, relation between grain-size and permeability and between grain-size and strength, plasticity, sedimentation of the finest particles, synthetic moulding sands, recovery of used sand and improvement of unused sand, and methods of sand dressing.

F. Roll, *New Methods of Testing Permeability of Moulding Sands* (Giesserei Zeitung, Dec. 1, 1925, vol. 22, pp. 723–725). Sands were tested at different degrees of wetness and the permeability appears to be lowest with lean sand (3·35 per cent. Al_2O_3) containing 0·1 per cent. and 15 per cent. of water; while with 5 up to 10 per cent. it is much more permeable to gas. Sand with clay up to 8·71 is of poor permeability, whatever the degree of wetness. In general the permeability largely depends on the kind of gas. Oxygen is the slowest gas to penetrate the sand, and oxygen is the element by the absorption of which in the metal the internal stresses in the casting are increased, leading to cracks and other defects. As the temperature of the mould rises the permeability of the sand diminishes.

F. Roll, *Tests of Grain-Size of Moulding Sands* (Die Giesserei, 1926, vol. 13, pp. 105–107). Various methods of testing grain-size and permeability of moulding sands are described. The washing method similar to that followed by Curtis is illustrated.

W. M. Weigel, *Preparation and Use of Industrial Special Sands* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). The author discusses the uses of sands for special industrial, chemical, and metallurgical purposes. The properties of these sands are described and micrographs are presented of the various types.

H. Ries, *The Use of Standard Tests for Moulding Sands* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). Sands show a wide variation in their character, and have a corresponding variety of uses, based mainly on the physical properties of the sand. The author points out the need for standard tests to determine and express these properties.

Control Tests devised for Steel Foundry Sand (Foundry, Feb. 15, 1926, vol. 54, pp. 157–158). A number of tests devised for moulding and core sand in the steel foundry are briefly described.

J. H. List, *Objects of Sand Binders* (Metal Industry, Mar. 12, 1926, vol. 28, pp. 253–254). The author discusses the properties which binders should possess, and the important question of their drying characteristics.

Simpson Intensive Foundry Mixer (Iron and Coal Trades Review, Dec. 11, 1925, vol. 111, p. 967). A brief description is given of the Simpson mixer for foundry sands.

Reducing Sand-Handling Costs (Iron Age, Nov. 26, 1925, vol. 116, pp. 1437–1439). The sand-handling equipment installed at the foundry of Allis Chalmers Manufacturing Co., West Allis, Wisconsin, is illustrated and described.

Moulding.—P. R. Ramp, *Standard Practice for Moulding* (Iron Age, Mar. 18, 1926, vol. 117, pp. 753–755, 816–817). The author points out the advantages of adopting a definite schedule in moulding operations, and gives particulars of standard practice recommended for moulding stern tubes for ships.

C. H. Brown, *Dry-Sand Moulding* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Nov. 12, 1925, vol. 32, pp. 415–416). Some of the factors involved in dry-sand moulding are discussed.

M. S. Clawson, *Metal Moulds by a New Process* (Iron Age, Nov. 12, 1925, vol. 116, pp. 1310–1313). Types of dies and moulds produced by the "Plastic" process are described and illustrated, but details of the process itself are not included. The process relates to the casting of steel and nickel to sufficiently close dimensions so that only grinding and finishing are necessary to produce dies for stamping or moulds. A material is used which will withstand the high temperature of molten steel or nickel, producing a casting free from scale. Brief particulars are given of the resistance type of electric furnace used in connection with the process.

F. C. Edwards, *Casting Design* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Jan. 28, 1926, vol. 33, pp. 65–68). The author discusses the factors involved in the design of castings, from both the moulding and metallurgical points of view.

N. Calder, *Some Notes on Mould and Core Drying* (Foundry Trade Journal, Nov. 12, 1925, vol. 32, pp. 413–414). The author outlines recent developments of the Oehm's heating element for the drying of moulds and cores.

Moulding a 10-Ton Salt Cake Pan (Metal Industry, Apr. 9, 1926, vol. 28, pp. 349–350). A brief account of the preparation of the mould; various expedients were adopted to avoid the necessity for making additional tackle, as only a small number of castings were required. The metal used consisted of 75 per cent. high-class pig iron and 25 per cent. scrap, twice melted, and the approximate analysis of the pig iron was:

	Per Cent.		Per Cent.
Combined carbon	0·50	Sulphur	0·07
Graphitic carbon	2·75	Phosphorus	0·40
Silicon	0·85	Manganese	0·80

The author has found this material to be very resistant to heat.

Moulding Cases (Metal Industry, Mar. 26, 1926, vol. 28, pp. 301–303). The making of moulding cases needs exceptional and expensive equipment out of all proportion to the work to be done. Various means which can be adopted to evade this expense are explained, and the pros and cons of using the foundry floor as part of the mould are discussed.

W. West, *Oil-Sand Cores and Production* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Jan. 28, 1926, vol. 33, pp. 69–73). The essential properties of oil-sand mixtures, classification of core oil, properties and character of linseed oil, drying or baking of oil-sand, and the application of oil-sand cores are discussed.

More Moulds made with Cores (Metal Industry, Mar. 5, 1926, vol. 28, pp. 229–231). Examples are given of the construction of moulds entirely or mainly with cores. Under certain conditions this method offers decided advantages.

Venting (Metal Industry, Feb. 26, 1926, vol. 28, pp. 205–206). Some of the mistakes made in venting are pointed out, and it is shown how the use of suitable facing sand and the moulder's skill will avoid the necessity for much artificial venting. A comparison is made of moulding as it used to be done and as it is now, with wax-vents, core-oils, &c., to assist the moulder.

B. Shaw and J. Edgar, *Loam Moulding Methods* (Foundry, 1925, vol. 53, Dec. 1, pp. 955–958; Dec. 15, pp. 999–1002; 1926, vol. 54, Jan. 1, pp. 21–23; Jan. 15, pp. 55–58; Feb. 1, pp. 112–115; Feb. 15, pp. 137–141; Mar. 1, pp. 184–187; Mar. 15, pp. 225–228; Apr. 1, pp. 275–279). A series of articles describing in detail methods of loam moulding, material, and equipment.

H. A. Schwartz, *Traces Steps in Long-Life Mould Advance* (Foundry, Jan. 1, 1926, vol. 54, pp. 42–44, 76). *Heat Control Limits Deterioration of Long-Life Moulds* (ibid., Feb. 1, pp. 92–94). *Long-Life Mould Temperatures Regulate Casting Properties* (ibid., Feb. 15, pp. 147, 149–150). *Permanent Moulds Favoured for Production Work* (ibid., Mar. 1, pp. 189–192).

Teaching the Young Idea to Mould (Iron Age, Jan. 28, 1926, vol. 117, pp. 272–273). Particulars are given of the course on the technique of moulding which has been drawn up by a committee of Indianapolis foundrymen. The course will be included in the curriculum of a number of the Indianapolis public schools.

E. Longden, *Moulding Machines* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1925, vol. 32, Oct. 29, pp. 370–372; Nov. 12, pp. 403–408). The author traces the development of methods of mechanical moulding.

G. Edginton, *Machines in Non-Repetition Foundries* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Dec. 3, 1925, vol. 32, pp. 463–466). An illustrated account of the application of jolting machines for the production of moulds of various sizes and shapes.

R. A. Fiske, *More Castings in Smaller Space* (Iron Age, Mar. 11, 1926, vol. 117, pp. 677–680). An illustrated description is given of the lay-out and method employed at the foundry of Nash Motors Co., Kenosha, Wisconsin. By the use of conveyors for transporting the moulds, and the use of moulding machines mounted on turntables, a great deal of floor space has been saved, and the output of castings has been doubled with fewer men employed.

Pattern-Shop Efficiency (Metal Industry, Apr. 2, 1926, vol. 28, pp. 325–326). The equipment required in the pattern-shop is dealt with, and some hints on attaining and preserving efficiency in the pattern-shop are given.

S. Carr, *The Patternmaker and Some of his Work* (Paper read before the Institute of British Foundrymen : Foundry Trade Journal, Dec. 17, 1925, vol. 32, pp. 513–518). A general illustrated account of several types of wood-working machinery used in the pattern-shop, and a method of pattern construction for pipes.

Centrifugal Casting.—E. J. Fox and P. H. Wilson, *The Principles of Centrifugal Casting as Applied to the Manufacture of "Spun" Iron Pipes* (Paper read before the Institute of British Foundrymen : Foundry Trade Journal, 1926, vol. 33, Jan. 14, pp. 23–26; Jan. 21, pp. 43–48). The authors describe the manufacture of pipes by centrifugal casting, and discuss the characteristics of "spun" iron. The methods described are those of the De Lavaud process as carried out at the Stanton Ironworks. The subject is discussed under the following headings: Speed of rotation of mould, rate of flow of metal, rate of traverse, casting temperature, metal composition, migration of elements, effects of elements, and mechanical tests (see also this Journal, 1924, No. II. p. 389).

Centrifugally Cast Pipes at the Works of the Stanton Ironworks Company, Ltd. (Iron and Coal Trades Review, Mar. 19, 1926, vol. 112, pp. 479–482). An illustrated description is given of the design and operation of the plant installed at the Stanton Ironworks, Nottingham, for the production of centrifugally cast pipes by the De Lavaud process.

J. E. Hurst, *Notes on the Centrifugal Casting Process, with Special Reference to the Hurst-Ball Process* (Paper read before the Association Technique de Fonderie de Belgique : Foundry Trade Journal, 1925, vol. 32, Oct. 29, pp. 361–365 ; Nov. 5, pp. 381–384). The most important application of the centrifugal casting process is in the production of cast-iron pipes. The production of castings for cylindrical liners, piston ring drums, and other similar purposes, is also carried out by the Hurst-Ball and other systems. The Hurst-Ball system has recently been applied to the production of large diameter cast-iron pipes. Steel castings in the form of wheels and hollow ingots are also produced in this country and America. The application of the process to the production of pipes in concrete and the lining of pipes with concrete or

other materials is a development of immense importance. In the principal processes spinning the mould about the horizontal axis or an axis slightly inclined to the horizontal is adopted. Spinning about the vertical axis is also used to a limited extent for short-length castings. The method of introducing the molten metal into the rotating mould is the principal feature which differentiates the various systems. The earliest method was the use of some form of bent funnel, suitably mounted, and projecting into the die parallel to the axis of rotation, allowing the molten metal poured from an ordinary ladle to be directed on to the surface of the mould in a continuous stream. The method of allowing the metal to issue from a series of nozzles in separate streams at equi-spaced distances over the length of the mould was adopted by Whitley. A more modern apparatus which has been developed takes the form of a tilting trough of cylindrical cross-section. A portion of the cylinder wall is cut away so as to form a horizontal weir edge of approximately the length of the casting to be produced. This trough is mounted in such a manner as to enable it to be tilted or partially rotated about its longitudinal axis. Various modifications of this apparatus have been introduced. A further method has been adopted in which the metal is poured on to the mould surface in a stream of narrow width. This stream is distributed evenly over the mould surface by moving the pouring spout longitudinally across the surface of the mould, or by moving the mould longitudinally over the pouring spout. This idea is embodied in the De Lavaud system. In the Hurst-Ball system relative longitudinal movement of the metal stream and the mould is obtained in a modified form of tilting trough in which the actual longitudinal movement of the mould and spout are avoided. In the form as adopted, the tilting trough consists of a cylindrical trough having a portion of the cylindrical wall cut away so as to leave a weir edge, which is a portion of a helix. When sand moulds are used the time of solidification of the molten metal is considerably prolonged. The use of sand moulds avoids the presence of chill. The use of hot metal moulds proposed by Cammen is also another means of eliminating the chill surface. Experience has definitely shown that these conditions can be obtained, using metal moulds either water-cooled or air-cooled. In the Hurst-Ball system cast-iron moulds are used of such a thickness that, with the rate of casting adopted, the inside surface temperature of the mould does not exceed 500° C. A great number of castings have been made by this system, and in no case has any annealing been necessary, and all the castings are soft grey and readily machinable. The adoption of annealing to eliminate the chill is one of the features of the De Lavaud system, and in this system hot castings are taken direct to the annealing furnace with the object of conserving as much heat as possible. The author also enumerates some of the defects encountered in castings produced by the centrifugal process, and the conclusion is drawn that these defects can be traced to the rate of velocity of pouring and the

spinning speed, either directly or indirectly. The paper concludes with a short bibliography of the literature on the subject.

Making Pipe by Centrifugal Process (Iron Trade Review, Apr. 15, 1926, vol. 78, pp. 999–1002). A description is given of the plant of the American Cast Iron Pipe Co., Birmingham, Alabama, for the manufacture of cast-iron pipes by the centrifugal process. The pipes are cast in a new type of refractory mould, for which a red loam moulding sand is used as a base.

Cleaning of Castings.—R. A. Fiske, *Hydraulic Washing of Castings* (Iron Age, Nov. 19, 1925, vol. 116, pp. 1383–1385). An illustrated description is given of the plant and methods in use at the foundry of the Allis-Chalmers Manufacturing Co., Milwaukee, for the cleaning of castings by hydraulic pressure. The operation is carried out in a specially constructed room of reinforced concrete. The doors are motor-operated and are packed to prevent leakage. The movable roof is made in three sections. Six nozzles project from the operator's room, which is three storeys high and situated near the door of the washing room. Wire-glass windows and electric reflectors are fitted in the operator's room. Hydraulic pressure for the nozzles is obtained by means of a centrifugal pump, rated at 800 gallons per minute, against a head of 900 feet. Turntables are provided to manipulate the castings during washing. All sand and core iron is recovered. Castings such as gears and fly-wheels are allowed to cool down to about 200° F. before washing, but less complicated castings are washed at a higher temperature without detrimental effect.

E. C. Barringer, *Cleans Castings Hydraulically* (Foundry, Dec. 1, 1925, vol. 53, pp. 951–954; Iron Trade Review, Nov. 19, 1925, vol. 77, pp. 1267–1269, 1318). The practice at the foundry of the Allis-Chalmers Manufacturing Co., Milwaukee, for the cleaning of castings by means of high-pressure columns of water is described and illustrated.

U. Lohse, *Modern Practice in Cleaning Castings* (Stahl und Eisen, Oct. 1, 1925, vol. 45, pp. 1661–1666). A general description of appliances for cleaning castings and the removal of dust. Cleaning is performed on grids with hoppers and boxes underneath from which the sand and dust is conveyed away by suction fans. Sand-blast machines employing a pressure of about 2 atmospheres are usually installed in German foundries, though in the United States pressures up to 4 atmospheres are common. The sand is recovered and used over and over again.

E. H. Trick, *Cleaning Grey Iron Castings* (Foundry, Jan. 15, 1926, vol. 54, pp. 71–72). The methods and machinery used at an American foundry for the handling and cleaning of castings are briefly described.

F. W. Neville, *Sand-Blasting and other Aids to Fettling* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Feb. 25, 1926, vol. 33, pp. 145–150). The different systems of sand-

blasting for the cleaning of castings are outlined, and the author discusses the influence of various factors on the efficient working of a sand-blast plant.

Special Castings.—C. M. Anson, *The Manufacture of Steel Wheel-Centres, Tyres, and Axles, at Newcastle, N.S.W., Australia* (Bulletin of the Canadian Institute of Mining and Metallurgy, Nov. 1925, No. 163, pp. 1035–1053). The author describes the processes used in the manufacture of steel wheel-centres, tyres, and axles at the works of the Commonwealth Steel Products Co. The steel for wheel-centres and tyres is made in a 6-ton Héroult furnace, the steel for axles being purchased in the form of billets. Particulars of the electric furnace and methods of melting are given, together with analyses of the steel. The tyres are forged and then rolled. The arrangement of the tyre mill is shown.

Making a 60-Ton Fly-Wheel (Foundry Trade Journal, Jan. 21, 1926, vol. 33, pp. 49–50). A brief description is given of the methods adopted for moulding and casting a large fly-wheel, which was made in six sections, using strong sand cores only.

P. Dwyer, *Turbine Wheel Manufacture* (Foundry, Jan. 15, 1926, vol. 54, pp. 45–48). The operations involved in the moulding of turbine wheels are described and illustrated.

R. Whitworth, *The Making of a 5-Foot Surging Drum in Halves* (Foundry Trade Journal, Feb. 11, 1926, vol. 33, pp. 117–118). The methods of pattern-making and moulding are described. These drums are used in coal mines where extensive hauling is carried out.

Clutch-Coupling Castings (Metal Industry, Dec. 4, 1925, vol. 27, pp. 537–539). These castings offer the particular difficulties of relatively massive forms and sharply varying sections. Sound castings were at first produced by the use of denseners, but later it was found that by using a metal whose composition endowed it with a narrow freezing range, and casting it through suitably regulated gates into a warm mould, castings of excellent structure were obtained without the use of denseners.

A. J. Richman and J. L. Francis, *Pistons for Internal Combustion Engines* (Metal Industry, 1925, vol. 27; Oct. 23, pp. 389–390; Nov. 6, pp. 437–438; Nov. 20, pp. 489–491). The authors consider that cast iron is better for making pistons than aluminium, provided the composition and structure of the metals are properly attended to. They describe and discuss what they have found to be the best moulding and metallurgical practice in the production of this class of goods, both small and large, and they also consider the chief metallurgical problems involved.

B. Hird, *Making a Road Roller* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Dec. 24, 1925, vol. 32, pp. 527–529). An illustrated description of the operations involved in the assembly of moulds for the production of castings for motor road

rollers. The whole of the mould and core are rammed on a Mumford jolt ramming machine. The castings weigh from 3 to 6 tons.

F. A. Schneider, *Mechanical Refrigerator Castings* (Iron Age, Jan. 21, 1926, vol. 117, pp. 205, 246). The author briefly discusses the production and characteristics of grey iron castings for use in refrigerators. In the foundry of the Gartland Haswell Rentschler Co., Dayton, Ohio, a cupola mixture is used consisting of 40 per cent. pig iron, 10 per cent. Mayari pig iron, 15 per cent. steel rails, and 35 per cent. sprue and scrap. The analysis of the molten metal is as follows: Silicon, 2·0 to 2·25; sulphur, under 0·07; phosphorus, under 0·20; manganese, 0·50 to 0·60; combined carbon 0·45 to 0·55; graphitic carbon, 2·90 to 3·10; chromium, about 0·20; and nickel, about 0·10 per cent. The castings have to withstand a very high pressure test of 260 lbs. The castings weigh about 10 lbs. and do not exceed $\frac{3}{16}$ inch in thickness. In pouring, large risers are essential in order to ensure soundness. The successful manufacture of these castings on a commercial basis depends on low phosphorus in the mixture and the use of a very low blast pressure.

R. Jones, *Moulding Cast-Iron Radiator Pipe* (American Machinist, European Edition, Feb. 6, 1926, vol. 63, p. 279E). The author describes a method of casting radiator pipes by arranging a moulding box in three parts and casting the radiators in a vertical position resembling an inverted ∩. Scale drawings are reproduced illustrating the preparation and use of the mould.

L. J. Barton, *Making Hard Iron Balls* (Foundry, Apr. 15, 1926, vol. 54, pp. 308–310, 322). The manufacture of iron balls for ball mills is described. Scrap is melted in an electric furnace, and the balls are cast in permanent moulds.

Foundry Equipment.—*The Foundry of Henry Ford & Son, Ltd.* (Foundry Trade Journal, Jan. 7, 1926, vol. 33, pp. 6–9). An illustrated description of the foundry of Henry Ford & Son, Ltd., at Cork, Ireland, for the production of automobile castings. The average production from the foundry is approximately 60 tons of iron castings per day. It is run almost entirely on the conveyor system, all transportation being effected by overhead runways.

Birtley Iron Company (Foundry Trade Journal, Jan. 7, 1926, vol. 33, pp. 11–12). Brief illustrated particulars are given of the foundry equipment of the Birtley Iron Co., Birtley.

Handling Heavy Castings (Foundry, Oct. 15, 1925, vol. 53, pp. 814–817). The layout and equipment of the foundry of the Dominion Engineering Works, Montreal, are described and illustrated. This concern is engaged in the production of heavy castings for paper-making, hydraulic, and hydro-electric machinery.

H. H. Moore, *Lifting and Shifting Appliances in Foundries* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Apr. 1, 1926, vol. 33, pp. 247–254). Cupola-charging and sand-handling appliances are discussed.

H. M. Lane, *Foundries Using Better Equipment* (Iron Age, Jan. 7, 1926, vol. 117, pp. 14–18). A general account of the developments in foundry practice. The tendency seems to be toward introducing sufficient sand, mould, and metal handling equipment in order to reduce manual labour to a minimum, and to increase the output per man-hour. Simpler forms of conveyors and sand-handling devices are also finding favour.

F. L. Prentiss, *Conveyors Nearly Triple Output* (Iron Age, Apr. 8, 1926, vol. 117, pp. 977–982). A detailed illustrated description of the conveyor system in operation at a large American foundry for the handling of moulds.

Training of Foundrymen.—E. Ronceray, *The Training of Foundrymen* (Foundry Trade Journal, Dec. 10, 1925, vol. 32, pp. 491–495). An account of the progress made in France in the training and education of foundry apprentices, artisans, and specialists, including particulars of the work of and subjects taught at the École Supérieure de Fonderie, Paris.

C. M. Morrin, *Practical Training for Foundry Work* (Iron Age. Oct. 22, 1925, vol. 116, pp. 1103–1105). An account of the system of training foundry apprentices at an American plant.

PRODUCTION OF STEEL.

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I.—*PROCESSES OF STEEL PRODUCTION.*

Crucible Steel.—J. A. Coyle, *Making High-Grade Steel* (Iron Trade Review, 1925, vol. 77, Dec. 10, pp. 1457–1459; Dec. 24, pp. 1592–1593; 1926, vol. 78, pp. 136–137; Jan. 28, pp. 261, 268–269; Feb. 11, pp. 397–399; Feb. 25, pp. 514–516; Mar. 11, pp. 636–637, 640; Mar. 25, pp. 806–807; Apr. 8, pp. 929–931; Apr. 22, pp. 1057–1059, 1062). A series of articles discussing the manufacture and uses of high-grade crucible steel.

Bessemer and Open-Hearth Processes.—E. Faust, *Production of Various Grades of Steel in the Basic Bessemer Converter* (Stahl und Eisen, Oct. 8, 15, 1925, vol. 45, pp. 1701–1704, 1739–1742). The analyses of pig irons most suitable for working up in the basic converter are given and practice in blowing different qualities of steel, such as for forgings, rails, hexagon bars, hard steel, and steel for wire is described. The following is a summary of practical experience. The higher the manganese in the pig iron, the higher will be the manganese content of the steel product and of the slag. The further dephosphorisation is carried, the greater is the amount of manganese and iron that become oxidised, and the lower is the manganese content of the product. The higher the silicon of the pig iron or the silica of the lime, the more do the manganese and iron become oxidised and the lower is the manganese of the steel. Too little lime increases the manganese in the slag.

A. Jung, *The Manufacture in the Converter of Steel for Drawn Hexagon Bars* (Stahl und Eisen, Nov. 10, 1925, vol. 45, pp. 1915–1917). Hexagon bars for the manufacture of nuts require to be made from a high-phosphorus low-carbon steel with fairly high manganese. The limits for phosphorus are 0·25 to 0·50 per cent., and for manganese 0·3 to 0·70 per cent. With manganese lower than 0·3 the material is apt to be red-short, and above 0·70, accompanied by high phosphorus, it becomes too hard. The practice followed is to use a high-phosphorus high-manganese mixer iron, and to stop the blow before

dephosphorisation is complete. With a 22-ton charge the limestone addition need not exceed 400 kilogrammes, and it is advisable to keep the temperature low. A satisfactory composition of the product is phosphorus 0·375, manganese 0·55, carbon 0·03 per cent.

J. Haag, *Use of Enriched Blast in the Basic Bessemer Process* (Stahl und Eisen, Nov. 12, 1925, pp. 1873–1878). Trials were made to ascertain the effect on the economy of the basic converter process of adding oxygen to the blast while blowing. One effect was that a much larger proportion of scrap could be used, thus lowering the cost per ton of materials charged. With 26 per cent. oxygen in the blast the saving worked out 1·06 shillings, and with 35·1 per cent. oxygen it was 2 shillings per ton. The blow was shortened by 2·75 minutes, using blast with 26 per cent. oxygen, and by 5·55 minutes when the oxygen was increased to 35·1 per cent. With natural air the total blowing time was 13·25 minutes. The iron loss was no greater with enriched than with natural air, and the quality of product was not affected in any way. The slag is less rich in phosphorus, which somewhat reduces the advantages of cheaper and quicker working.

F. Bernhardt, *Present Position of the Basic Open-Hearth Process in Comparison with the Basic Bessemer Process* (Stahl und Eisen, 1926, vol. 46, Jan. 7, pp. 1–7; Jan. 14, pp. 39–44; Jan. 21, pp. 73–78; Feb. 4, pp. 137–142). A critical examination of the various processes for the manufacture of basic steel is presented, with an account of the development of the so-called Königshütte process. This is a continuous duplex process carried out in two tilting open-hearth furnaces. In the first furnace the preliminary refining is performed by the dephosphorisation and elimination of other impurities. A Wellman 300-ton tilting furnace is used for this operation. Every 4½ or 5 hours 80 tons of pig is run in from a mixer, the total charge per 24 hours being about 400 tons. When the quantity in the furnace reaches 230 tons, 80 tons are run off to the finishing furnace, which is of 150 to 200 tons capacity, and a fresh charge of 80 tons is run into the first furnace. The finishing operations proceed in the second furnace, and when decarburisation has reached a certain point it receives a second charge of 80 tons from the the first furnace, and about 20 tons of scrap are added and the usual ore and lime additions are made. The total charge in the second furnace now amounts to about 180 tons. This is finished and some 100 tons are tipped off into two 50-ton ladles, in which the final deoxidation is made. The output of finished steel per twenty-four hours is then about 500 tons. The record of the metallurgical operations is given in tables. Similar descriptions follow of the Hoesch process, the Dortmunder Union process, and the Witkowitz process, the last named being the Talbot process with certain recent modifications. A comparison is then made of the basic open-hearth and basic Bessemer processes, both as regards output, cost of installation, and cost of working. In heat economy the basic Bessemer is in no way superior to the open-hearth, and as regards quality and losses of materials it is

inferior. Costs of working depend upon several factors, and in certain circumstances the cost of production may be higher or lower with either method.

Acid versus *Basic Steel* (Machinery, Apr. 22, 1926, vol. 28, pp. 102–103). Good basic steel is as good as acid steel; the general feeling against basic steel seems to be based on the idea that it is better to use a material which has never contained much sulphur and phosphorus rather than one from which these impurities have been removed. The very exacting and modern specifications of the Air Board place practically no limitation on the use of basic steel, so far as plain carbon steels are concerned.

A. Dorman, *Presidential Address* (Proceedings of the Cleveland Institution of Engineers, Session 1925–26, No. 1, pp. 12–38). Progress in basic open-hearth practice in the Cleveland district is discussed, with special reference to the practice at the plants of Dorman Long & Co., Ltd. The present plant at the Clarence Steelworks consists of four 45-ton furnaces erected in 1900–1901, four 50-ton furnaces erected in 1903, and one 75-ton furnace erected some years later. Improvement in practice has resulted in a steady increase in output. In 1902 the average weekly output of the 45-ton furnaces was 350 tons per week. The furnaces were charged with molten iron, no scrap being used. Since that date the average weekly output per furnace has been as follows:

	Tons.
1906	420
1911	590
1925 (8 months) . .	857

The plant at the Britannia Works consists of furnaces of 50, 60, and 80 tons capacity, the dimensions of which are tabulated. The weekly output per furnace at these works was as follows:

1905	512 tons	from	14	charges
1906	830 ,,	,,	10	,,
1920	883 ,,	,,	11	,,
1924	1060 ,,	,,	13	,,

The increase in output per furnace by 300 tons in 1905–6 was due to enlarging the furnace dimensions and improved mixer practice. From 1920 onwards the improvement in output is due to increase in the size of the charge.

At the Redcar Works there are seven large fixed furnaces and three 90-ton tilting furnaces. The dimensions of the fixed furnaces are given, the output being 1050 to 1200 tons per week. At the Acklam Works (formerly the North Eastern Steelworks) tilting furnaces of 175–200 tons capacity have been erected, from which a weekly output of 1400 tons per furnace has been obtained. In 1901 the first mixer was erected at the Clarence Works. It was of the inactive type and of 200 tons capacity. In 1907 an active mixer of 400 tons capacity was erected and is still in

operation. This mixer removes 50 per cent. of the silicon and 42 per cent. of the sulphur from the iron. A 400-ton mixer at the Redcar Works removes 74 per cent. of the silicon and 34 per cent. of the sulphur. In this country mixers of 750 to 1000 tons capacity have been installed, but in America there is a tendency to dispense with mixers, attention being given to the production of a suitable iron low in silicon and sulphur. On the Continent non-active mixers are the rule, frequently up to 1000 tons capacity. The advantages of mixers are pointed out. Great economy has been effected by the use of modern types of gas-producers. In early days fuel consumption was about 10 to 12 cwts. per ton of steel. At the present time it is about 4 to 5 cwts. With the best producer practice 80 to 85 per cent. of the heat units in the coal are available in the gas. Coke-oven gas mixed with producer-gas was first used at the Clarence Works in 1916, and the coal consumption per ton of steel has been reduced by 42 per cent., and in the case of one furnace the coal consumption has been reduced to 2·39 cwts. per ton of steel made. The economy effected by the introduction of waste-heat boilers and economisers is also pointed out.

P. Williams, *Basic Open-Hearth Process* (Proceedings of the Lincolnshire Iron and Steel Institute, 1918–1920, vol. 1, pp. 1–26). A short account is given of the early history of the basic open-hearth process in England, and the developments of the process are discussed. The results of mechanical tests on basic steel are tabulated, and the results obtained on acid steel are included for comparison.

C. P. Williams, *Some Notes on Open-Hearth Furnaces* (Proceedings of the Lincolnshire Iron and Steel Institute, 1918–1920, vol. 1, pp. 58-62). A brief discussion of the dimensions of basic furnaces and size of regenerators. Tables and graphs are given showing that for a furnace of a given tonnage the bath area for hot metal practice is greater than when the scrap process is used.

E. Kerl, A. Drieschner, and W. Bertram, *The Höntrop Works of the Bochum Company* (Stahl und Eisen, 1926, vol. 46, Mar. 31, pp. 429–436, Apr. 8, pp. 468–475). The authors describe the new steelworks built by the Bochumer Verein at Höntrop in order to ensure to the Company a regular supply of steel for working up into their numerous special products. Space is provided for four 100-ton tilting furnaces of the firm's own design. Two of the furnaces are already built. These are fitted with Friedrich ports and are fired entirely with a mixture of coke-oven gas of about 4000 calories and blast-furnace gas of 1000 calories, the average heat value of the mixture being 1800 calories per cubic metre, corresponding to a proportion of 1 to 2·7 of the gases. The works are equipped for the production of seamless tubes and fittings on a large scale and using the most up-to-date appliances. The fuel gases are brought to the steel-furnaces from the blast-furnaces and coke-ovens situated some distance away, the total length of the mains for the purpose being about 8 kilometres. No solid fuel of any kind is used in the works.

E. Herzog, *The Use of Liquid Pig in the Scrap Pig-Iron Process as Worked in the Open-Hearth Furnace* (Stahl und Eisen, 1926, vol. 46, Mar. 18, pp. 357–361). In certain steelworks operating independently of blast-furnaces, cupolas have been installed for melting the pig iron previous to charging. The author discusses the economy of this method of operation, and calculates that at Rothe Erde, where it is employed, the cost of melting the pig iron amounts to 5·70 marks, while the saving in the refining operations is 10·80 marks per ton of steel produced. The number and size of cupolas required for a given steelworks plant are stated, and the modifications involved in the working of the scrap pig-iron process are described.

E. Herzog, *Remelting Pig Iron in the Open-Hearth Process* (Iron and Coal Trades Review, Apr. 23, 1926, vol. 112, pp. 700–701). An English abstract of the report of the Steelworks' Committee of the Verein deutscher Eisenhüttenleute noted above.

G. R. Bashforth, *Elimination of Impurities from the Basic Bath* (Paper read before the Sheffield University Metallurgical Society: Foundry Trade Journal, Dec. 31, 1925, vol. 32, pp. 559–560). A brief discussion of the reactions involved in the removal of impurities in the basic open-hearth process.

Sulphur Taken Up from Fuel Gases (Iron Age, Dec. 10, 1925, vol. 116, pp. 1586–1587). An abridged translation of an article by A. Jung which appeared in Stahl und Eisen, July 31, 1924, vol. 44, pp. 911–914 (see this Journal, 1924, No. II. p. 395). The use of brown-coal producer-gas in the open-hearth furnace, and its effect on the sulphur content of the finished steel, were investigated.

J. Bronn, *Sulphur in Producer-Gas for the Open-Hearth Furnace* (Iron and Coal Trades Review, Feb. 19, 1926, vol. 112, p. 309). An English translation of a report of the Steelworks Committee of the Verein deutscher Eisenhüttenleute, and published in full in Stahl und Eisen, Jan. 21, 1926, vol. 46, pp. 78–80.

J. L. Keats and C. H. Herty, *Elimination of Metalloids in the Basic Open-Hearth Furnace* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). The authors present data on all the factors that affect the elimination of metalloids in the basic open-hearth furnace. A test heat was made in a standard 100-ton furnace at the works of the Lackawanna Steel Company, New York. Graphs are given showing the manner, proportion, and speed of elimination of each of the several metalloids from the bath, and the changes in composition of the slag during the progress of the heat. Wide variations in composition of the bath occur after ore additions, therefore it is necessary, in studying the rate of elimination, to take the whole bath into consideration and not to use the middle door alone for sampling. The bath is of uniform composition under finishing conditions, and a test from any door during this period will represent the entire bath. With large amounts of excess air for combustion and with a coal analysing 1·18 per cent. of sulphur, desulphurisation of the bath takes place.

There is a strong possibility that the gas given off from the decomposition of the limestone desulphurises the bath. The erosion of the furnace lining is dependent, for a given amount of slag, primarily on the silica content and fluidity of the slag. During the working period the fluidity and iron oxide content of the slag are controlling factors. The rate of solution of lime from the limestone into the slag is dependent, for a given amount of slag, on the fluidity of the slag and on its iron oxide and silica content.

Making Basic Open-Hearth Steel (Iron Age, Oct. 22, 1925, vol. 116, pp. 1109–1113). An account of an informal discussion which took place at the Open-Hearth Conference held under the auspices of the American Institute of Mining and Metallurgical Engineers, in Oct. 1925. No papers were presented, and the subjects discussed included furnace design, practice, yield, and refractories. Particulars were presented of the performance of furnaces fired with natural gas and oil fuel, a new type of oil burner, life of ingot moulds, and the use of clinker for patch work.

E. A. Whitworth, *The Basic Open-Hearth Practice* (Transactions of the American Society for Steel Treating, Dec. 1925, vol. 8, pp. 739–747). The history of basic open-hearth practice is outlined, and furnace design and melting practice for high-grade carbon forging steel are briefly discussed.

C. H. Herty, *Chemical Equilibrium of Manganese, Carbon, and Phosphorus in the Basic Open-Hearth Process* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). The author presents the results of a study of the open-hearth process from a physico-chemical viewpoint. Experiments were carried out in small laboratory furnaces and in standard 100-ton furnaces. The behaviour of manganese, carbon, and phosphorus are quantitatively explained. The action of "residual" manganese is discussed with reference to its relation to iron oxide dissolved in the metal. The solubility of carbon monoxide and its relation to dissolved iron oxide is given. The equation for phosphorus elimination has been tested out on a 200-ton furnace and the results are included in the paper. It is concluded that the amount of residual manganese, excepting when the slag contains over 5·0 per cent. P_2O_5, is controlled by the total manganese charged, the amount of manganese volatilised, the iron oxide content of the slag, the basicity of the slag, the slag volume, and temperature. The amount of iron oxide in the metal is not controlled by the residual manganese present. The amount of carbon in the metal depends on the concentration of iron oxide in the slag and on the temperature. The amount of phosphorus in the metal depends on the total phosphorus in the charge, the iron oxide content of the slag, the basicity of the slag, the slag volume and the temperature.

H. D. Hibbard, *Differences in Open-Hearth Boils* (Iron Age, Dec. 3, 1925, vol. 116, pp. 1511–1513); *Ten Types of Open-Hearth Boils* (Dec. 10, pp. 1605–1606); *Open-Hearth Boils of High Vigour* (Dec. 17,

1925, pp. 1671–1672). In these three articles the author analyses the causes and effects of the action of the bath in the open-hearth process designated as boil. Ten types of boil are recognised, classified according to degree and violence. The author discusses each type in detail.

C. Pierce, *Making Rimmed Steel* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). For the production of rimming steel in the open-hearth furnace the author recommends a charge consisting of 40 per cent. pig iron and 60 per cent. scrap with no iron ore. This is based on the fact that the silicon in good rimming steel must be eliminated to a very high degree. Good steel scrap should be used, and a sufficient amount of limestone should be added to give mushy slags when working loose from the bottom. To prevent too much oxidation while working the heat the bath temperature and the oxidising influence of the slag must be controlled. In a heat finished with a slag too rich in oxygen, ferrous oxide is likely to be transferred to the metal. With a very hot bath the metal has a greater solvent power for ferrous oxide, regardless of its carbon content. The steel must not be over-oxidised, but should contain a sufficient amount of carbon monoxide to produce the rimming effect. Silicon in the bath protects the carbon from oxidation and lessens the vigour of the boil. It thus limits the amount of carbon monoxide formed. In the finished steel the silicon should be down to a trace; for soft steel 0·08 to 0·10 per cent. carbon and 0·30 to 0·35 per cent. manganese are preferred.

R. Furness, *Acid Open-Hearth Steel Melting Practice* (Transactions of the American Society for Steel Treating, Dec. 1925, vol. 8, pp. 728–738). A brief discussion of the general principles of acid open-hearth practice.

R. S. Kerns, *Melt High-Chromium Alloys in Acid Furnace* (Iron Trade Review, Mar. 25, 1926, vol. 78, pp. 812–814). Acid electric furnace practice for melting high chromium steel is discussed.

A. McCance, *Open-Hearth Steel Furnace Reactions* (Royal Technical College, Metallurgical Club Journal, Glasgow, 1925, No. 4, pp. 4–8). A discussion of the physical chemical reactions taking place in the open-hearth furnace.

R. P. Smith, *The Open Hearth* (Royal Technical College Metallurgical Club Journal, Glasgow, 1925, No. 4, pp. 18–22). A brief discussion of open-hearth practice.

C. G. Atha, *Some Comparisons between American and British Methods of Iron and Steel Production* (Proceedings of the Lincolnshire Iron and Steel Institute, 1918–1920, vol. 1, pp. 89–105).

G. L. Sakharoff, *The Carbon Scrap Process* (Transactions of the Institute of Economic Mineralogy and Petrography, 1924, No. 11. Printed in Russian with summary in English). In the carbon scrap process coke or some other carburiser is used in place of the usual pig iron. If coke is used it should contain less than 1 per cent. of sulphur. The author describes the process in detail.

Dimensions and Output of German Open-Hearth Furnaces (Iron and Coal Trades Review, Nov. 13, 1925, vol. 111, pp. 774–777). An English translation of a section of the paper by H. Bansen, published in Stahl und Eisen, Apr. 2, 1925, vol. 45, pp. 489–507. (See also Iron and Coal Trades Review, Sept. 4, 1925, vol. 111, pp. 351–355.)

K. Huessener, *Combustion in the Open-Hearth Furnace, with Special Reference to Automatic Control* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). This paper consists largely of calculations worked out from observations of open-hearth furnaces with or without control, the control being by means of an induced-draft fan operated through the regenerator chambers. Results are given of furnaces operated with and without control, showing the improvements obtained in output and fuel consumption when a system of control is used. The author emphasises the necessity of a large number of exact balance sheets under varying conditions, laying special stress on the need of particular care in temperature measurements. Preheating temperatures for the present type of checker chambers are naturally low, and on new construction particular care should be taken not only to increase the size of the checker chamber but also to obtain equal distribution of outgoing and ingoing gases over all parts of the checker chambers. The results obtained from an open-hearth furnace depend on the amount of gas completely burned for a given period, and on as low an excess of air as is possible. This necessitates the installation of forced-draft and induced-draft fans and equipment with automatic combustion control.

W. Hülsbruck, *The Decomposition of the Gases in the Regenerators of an Open-Hearth Furnace Heated with a Mixture of Blast-Furnace and Coke-Oven Gas* (Stahl und Eisen, Oct. 15, 1925, vol. 45, pp. 1746–1751). From a consideration of all the chemical reactions capable of occurring in the regenerators during the passage of a mixture of blast-furnace and coke-oven gas, the author deduces that any decomposition should result in no loss, but rather a gain, in latent heat. Some further results of the work may be summarised as follows. During the preheating an increase in oxygen and carbon monoxide is brought about with a decrease in the carbon dioxide, methane, and heavier hydrocarbon contents. These chemical reactions cause an increase in the gas volume and the precipitation of some free carbon. Temperature, duration of heating, and gas composition have a large influence on the inter-reactions, but, on the other hand, the amount of water formed is practically dependent on the free oxygen present only. From 480° to 1070° C. a loss up to 1·5 per cent. of heat of combination is found, while above 1070° an increase up to 4 per cent. occurs with rising temperature up to 1300° C.; in all cases, however, the calorific value decreases. The increase in sensible heat increases by 15 to 18 per cent. with a regenerator temperature of 1000° to 1100° C. Despite the decrease in calorific value, preheating the gas increases the flame temperature. Long heating of the gas causes a rise in the latent heat. The free

carbon produced is partly regasified up to 20 to 45 per cent., according to the temperature; the remaining free carbon passes practically entirely into the furnace space.

J. Arnoul de Grey, *The Influence of Velocity in Heat Regenerators* (Chaleur et Industrie, Feb. 1926, pp. 102–107). The author is of opinion that the ordinary method of calculation adopted in designing regenerators is misleading, in that only the weight of the heat-exchanging material is considered, and not its surface. The influence of the velocity of the gases through the regenerators is also discussed, and the results of the author's experience are set forth.

Automatic Regulator for Gas-Fired Furnaces (Engineering, Oct. 30, 1925, vol. 120, pp. 555–556). An illustrated description of an automatic regulator manufactured by the Selas Gas and Engineering Co., Ltd., Manchester, for controlling the air and gas supplies to furnaces. Fluctuations in the pressure of the air or gas supplies are corrected, so that the final ratio of air and gas entering the furnaces, and their quantities, remain constant. Oxidising, neutral, or reducing conditions can be maintained in the furnace.

Machine Repairs Furnace Slag Lines (Iron Age, Dec. 17, 1925, vol. 116, pp. 1673–1674). An illustrated description is given of a machine for repairing the slag lines in open-hearth furnaces. In operation dolomite is fed from an overhead hopper through a chute into the groove of a pulley. Besides this grooved pulley the throwing mechanism consists of three smaller pulleys and an endless belt. When the belt covers the groove the dolomite is thrown on it by centrifugal force and is made to assume its velocity. When the belt bends over the discharge pulley the material leaves the machine in a continuous stream. The throwing mechanism is driven by an electric motor, and the stream of dolomite may be swung through both horizontal and vertical planes.

Suspended Open-Hearth Roof Survives 428 *Heats* (Iron Trade Review, Dec. 24, 1925, vol. 77, pp. 1585–1588). Illustrated particulars are given of the use of suspended roofs for open-hearth furnaces in America. The arrangement for supporting the roof is shown. It can be applied to existing furnaces without change in furnace lines. The silica tiles are hung by exterior supports which are protected from the furnace temperature. The weight of the roof is carried vertically, and therefore the load carrying requirements of the tiles are reduced to their own weight. Compensation for expansion and contraction is provided by a series of compression springs. The same principle has been employed in suspended arches for practically all types of metallurgical furnaces.

T. C. Fetherston, *Improved Oxygen Lance for Open Hearth* (Blast-Furnace and Steel Plant, Sept. 1925, vol. 13, p. 374). In order to prevent the rapid burning away of the steel end of the lance, a hardwood sleeve is fitted. This is at first rapidly charred down to tapered point, but in this condition the wood is consumed very slowly

and protects the steel end of the lance itself. Often the "tip" can be used for several tappings, and replacement is a matter of only a moment.

Steelworks Tools (Machinery, 1926, vol. 27, Jan. 21, pp. 537–544; Feb. 11, pp. 633–640; Mar. 4, pp. 737–740). An illustrated description of heavy plant used in steelworks, including sawing machines, git slotters, ingot cutters, slicers and trepan boring machines, shears, steam-hydraulic intensifiers, straightening machines, and machines for dealing with rails.

Practical Capacity 50 *Million Tons* (Iron Age, Jan. 21, 1926, vol. 117, p. 211). The report of a committee appointed by the American Iron and Steel Institute to make a survey of the steel-making capacity of the United States has been presented. Existing steel plants are estimated to be capable of producing 50,000,000 tons of steel ingots per annum. The capacity of existing blast-furnaces is rated at 45,000,000 tons a year.

Waste-Heat Utilisation.—F. H. Willcox and J. C. Hayes, *Waste-Heat Boilers in Steel Mills* (Paper read before the Western Society of Engineers, Chicago, Nov. 16, 1925: Iron Age, Dec. 3, 1925, vol. 116, pp. 1516–1520). In a boiler utilising waste heat at 1200° F. the radiant heat available is less than one-tenth of that available in a direct-fired boiler where temperatures of 2700° or over prevail. Therefore rapid water circulation in a waste-heat boiler is not a prime requisite, but it is important that maximum heat recovery by conduction and convection be accomplished. The most intimate contact of gases and water-heat heating surface should take place. It is essential that the waste gases pass as close to the heating surface as possible, with a positive scrubbing or tumbling action taking place. This can be brought about by close tube spacing in water-tube boilers or the use of small-diameter tubes in fire-tube boilers. In either case the gas must travel at a velocity higher than is usual by natural draft alone. The water-tube boiler at a given mass velocity and tube diameter has a higher heat transfer rate than the fire-tube type, but the friction loss in the fire-tube boiler is much less. Consequently the rate of heat transfer may be so increased in the fire-tube boiler as to exceed that of the water-tube type, while keeping the friction loss the same. No practical combination of tube spacing and baffling of water-tubes can bring about as close a contact of the gas with the heating surface as is possible in a fire-tube boiler for the same draft loss. The results of tests of two fire-tube boilers utilising the waste heat from open-hearth furnaces at an American plant are tabulated. Experience has shown that the induced draft incident to the use of waste-heat boilers is an advantage in regular furnace operation. The general arrangement of the waste-heat boilers at the plants of the United Alloy Steel Co., Canton, Ohio, and the National Malleable and Steel Castings Co., Melrose Park, Illinois, are illustrated. The authors also show the effect of the recovery of waste heat from open-hearth furnaces on the cost

of finished steel, and briefly discuss the utilisation of waste heat from gas-engines.

Gas-Fired and Waste-Heat Boilers (Colliery Engineering, 1926, vol. 3, Mar., pp. 122–124; Apr., pp. 166–167, 182). The leading features of the various types of gas-fired and waste-heat boilers are described and illustrated.

V. J. Azbe, *Industrial Furnace Efficiency* (Mechanical Engineering, mid-Nov. 1925, vol. 47, pp. 1061–1064). A consideration of the heat losses encountered in industrial furnace operation, such as radiation losses, losses due to dry products of combustion, dilution of the products of combustion, and incomplete combustion. The application of waste-heat boilers to industrial furnaces is discussed.

R. D. Keillor, *Surplus Heat and the Avoidance of Waste* (Gas Journal, Dec. 16, 1925, vol. 172, pp. 731–732). In this paper, read at a meeting of the Scottish Junior Gas Association on Dec. 5, 1925, the author distinguishes between waste heat and surplus heat, and suggests methods of minimising the former and utilising the latter in boilers, gas-producers, and other apparatus.

Electric Steel Furnace Practice.—W. S. Gifford, *Electric Furnaces in* 1925 (Electrician, Nov. 27, 1925, vol. 95, pp. 617, 627). A review of the development of electric furnaces, and of their application in industry. Very little progress has been made in the electric steel-melting furnace, but medium-frequency melting furnaces have been introduced with success in the melting of some non-ferrous alloys. Progress is still slow, but there are some hopeful signs for the future. It is interesting to note that at least forty electric steel furnaces built in Great Britain have been supplied to the Continent, whereas hardly any foreign-built furnaces have been sold in England.

F. Hodson, *Electric Furnace Progress in* 1925 (Blast-Furnace and Steel Plant, Feb. 1926, vol. 14, pp. 66–71, 108).

P. H. Brace, *A High-Frequency Induction Furnace Plant for the Manufacture of Special Alloys* (Journal of the American Institute of Electrical Engineers, 1925, vol. 44, pp. 992–1000). The production of metals and alloys of high purity at the plant of the Westinghouse Company is described. The equipment, details of which are given, include an electrolytic refining plant, a high-frequency power plant, and a high-frequency furnace plant. A production cost analysis, based on a monthly output of 30,000 lbs., indicates 16.55 cents per lb. for electrolytic iron and 36.62 cents for iron-nickel alloys.

F. Wever, *The High-Frequency Induction Furnace* (Stahl und Eisen, Apr. 22, 1926, vol. 46, pp. 533–536). An illustrated description is given of an installation of high-frequency furnaces, with a discussion of the advantages of such furnace as compared with the low-frequency furnace with annular hearth.

G. Ribaud, *High-Frequency Electric Furnaces for very High Temperatures* (Revue Universelle des Mines, Apr. 15, 1926, vol. 10, pp. 90–92).

The spiral carrying the electric current is wound on a suitable tube, inside which is fixed a second tube of highly refractory material, such as fused silica. The crucible is of graphite and is heated by induction; heat insulation is obtained by filling the space between the crucible and the refractory tube with lampblack. A cover of porous carbon is fitted, and has holes provided to take off any gas. Precautions are taken to cool the outside of the carbon parts in order to prevent their burning away. Provision can be made for taking optical pyrometric readings, in which case an inert gas is circulated through the furnace to remove fumes which would give rise to errors in the pyrometer readings. In a furnace of 100 cubic centimetres capacity a temperature of 3000° C. has been obtained for an expenditure of energy of 7 kilowatts.

Induction Furnace Progress (Electrician, Nov. 27, 1925, vol. 95, pp. 620, 627). A description of the new Ribaud design of furnace, using high-frequency induction. The spark-gap used with this furnace rotates, instead of being stationary, as in other similar types of furnace, and a higher power factor is, on that account, claimed.

E. F. Northrup, *Inductive Heating* (Journal of the Franklin Institute, Feb. 1926, vol. 201, pp. 221–244). The paper describes the evolution of the idea that heat might be developed by an influx of electro-magnetic energy. High-frequency furnaces and the plant for producing the necessary high-frequency currents are illustrated.

A. Muller-Hauff, *The Qualitative and Economic Importance of Acid Electric Steel* (Stahl und Eisen, 1926, vol. 46, Feb. 18, pp. 213–218; Mar. 4, pp. 289-293). The metallurgical operations in the production of acid steel in the electric furnace are described, and the results are presented of a number of comparative tests on acid electric and basic electric steel and open-hearth steel of similar composition. Three series of steels were investigated: (*a*) plain carbon steels, with carbon at 0·50 to 0·54 per cent.; (*b*) nickel-chromium steels, with carbon 0·30 to 0·33, nickel 3·90 to 4·10, and chromium 0·73 to 0·80 per cent.; (*c*) nickel-chromium steels, with carbon 0·30 to 0·32, nickel 2·73 to 2·90, and chromium 0·95 to 1·00 per cent.; the phosphorus ranged from 0·01 to 0·03, and the sulphur from 0·007 to 0·025 in all cases. The electric steels are superior to the basic open-hearth in all respects, particularly as regards elastic limit, tensile strength, and elongation, while a comparison of the electric steels alone shows that the acid steels have better tensile properties than the basic, except that the former show somewhat lower values for contraction. On the other hand, on account of the cheaper raw materials, the cost of production of basic steel is considerably less than that of acid steel, especially in the open-hearth. The acid electric furnace is therefore limited mainly to the production of steel castings, while on the ground of price the basic steel, either electric or open-hearth, is always more in demand for ordinary commercial steels. Photographs of the broken bars are shown.

New Electric Furnace (Iron Age, Nov. 26, 1925, vol. 116, p. 1453). A brief description is given of the Kay electric steel furnace. It is of

the tilting type, in which the body is mounted to rotate on a horizontal axis with a pouring spout at each end. The electrodes are adjustable.

J. A. Seede, *Electric Melting Furnaces* (Iron and Steel Engineer, 1925, vol. 2, pp. 368–374). The author discusses the improvements made in electric furnace equipment, and compares the electric capacities of modern furnaces with those in operation in 1910.

Duplex Furnace Operation by a Steel Company (Electrical World, 1925, vol. 86, p. 854). A brief account is given of the multiple 3-ton electric furnace installation at the Burnside Steel Co., Chicago. One set of electrodes and a single unit of control and transformer equipment is used for two furnaces. One furnace is under power while the other is being tapped, so that little time is lost between the heats. Both furnaces produce 20 tons of steel per ten-hour day.

F. T. Sisco, *Electric Furnace Steel* (Transactions of the American Society for Steel Treating, Dec. 1925, vol. 8, pp. 748–781). A discussion of basic electric furnace practice, with special reference to American practice.

A. C. Lange, *Electric Furnaces Raise Steel Production* (Electric World, 1925, vol. 86, pp. 370–371). The replacement of a 1½-ton single-phase electric furnace by a 1½-ton three-phase Moore electromelt furnace resulted in an increase in production of 50 per cent. The current consumption was 600 kw.-hours. The charge consisted of boiler plate, drop forgings, shop scrap and punchings. The electrode consumption was 12 to 18 lbs. per ton of steel.

J. H. Hruska, *Chromium-Nickel Electric Ingots* (Iron Age, Dec. 31, 1925, vol. 116, pp. 1801, 1845–1846). The author records the operation and gives balance-sheets of basic electric furnace practice for the production of chromium-nickel steel.

F. E. Clark, *Electric Alloy Steel* (Year-Book of the American Iron and Steel Institute, 1925, pp. 319–329). A discussion of basic and acid electric furnace practice, with special reference to American practice.

R. S. Kerns, *Economic Operation of Electric Furnaces* (Blast-Furnace and Steel Plant, Feb. 1926, vol. 14, pp. 133–135). The article gives the results of tests made during the operation of five standard sizes of melting furnaces.

A. Coutagne, *Heat Balance and Efficiency of the Electric Furnace as Compared with other Metallurgical Furnaces* (Technique Moderne, 1925, vol. 17, pp. 541–545).

J. H. Hruska, *Analyses of Basic Electric Furnace Steel and Furnace Materials in Europe* (Blast-Furnace and Steel Plant, Dec. 1925, vol. 13, pp. 490–491). Tables are given showing the analyses of steels, alloy steels (castings and ingots), basic electric furnace slags, the usual additions (ferrous and non-ferruginous) and refractories. Some figures for first metal tests, and of the composition of the volatile dust from electric furnaces, are also given. About 100 analyses are included, and they are believed to comprise practically everything of importance in European electric steel-making.

C. Becker, *A New Carbon Electrode* (Stahl und Eisen, Jan. 14, 1926, vol. 46, pp. 44–46). A new design of a composite electrode is described and illustrated, consisting of a core of highly burnt carbon with an outer casing of stamped carbon enclosed in a wire net. Strips of metal are fitted between the burnt core and the outer electrode. The core will bear graphitisation without breaking, and can therefore carry a heavy current. The metal strips conduct the current to the lower and more resistant end of the electrode, and near the point they melt away, producing a good distribution of current in the outer electrode. The composite electrode will readily carry a current of 250 volts pressure.

J. A. Seede, *Automatic Arc Furnace Control* (Blast-Furnace and Steel Plant, Dec. 1925, vol. 13, pp. 482–484). An illustrated description of modern automatic electrode control for arc furnaces used in melting and smelting operations.

M. Sem, *Söderberg Electrode Shows Low Operating Cost* (Chemical and Metallurgical Engineering, Nov. 1925, vol. 32, pp. 865–866). A few notes on the consumption of these electrodes and on the number installed and projected.

New Process of Caulking Furnace Electrodes (Electrical World, 1925, vol. 86, p. 1158). It is stated that a process has been developed for caulking the space around furnace electrodes where they pass through the shell of the furnace. The material used consists of tar or pitch, which forms a fluid seal around the electrodes at the higher temperatures.

Electric Control Gear for Iron and Steel Works (Iron and Coal Trades Review, 1926, vol. 112, Mar. 5, pp. 386–388; Mar. 12, pp. 428–430; Mar. 19, pp. 488–489; Mar. 26, pp. 526–528). Numerous types of electric control devices applicable to iron and steel works are described and illustrated.

Scrap Specifications.—*Revised Scrap Specifications* (Iron Age, Feb. 11, 1926, vol. 117, pp. 411–412, 455–456). Particulars are given of the revised specifications covering iron and steel scrap for the use of blast-furnaces, steel plants, and foundries, and the proposed specification covering iron and steel scrap for iron rolling-mills, drawn up at a meeting held under the auspices of the Division of Simplified Practice of the Bureau of Standards, Washington.

Steelworks Equipment and Plant.—J. Horton, *British Steel Interests Push Reconstruction Plans* (Iron Trade Review, Nov. 12, 1925, vol. 77, pp. 1215–1218, 1220). A general account, with illustrations, of the improvements carried out at the Acklam Iron and Steel Works of Dorman Long & Co., Middlesbrough.

Messrs. Brown Bayley's Steelworks (Engineering, 1925, vol. 120; Aug. 14, pp. 192–196; Aug. 28, pp. 256–258; Sept. 18, pp. 343–345; Sept. 25, pp. 374–375; Oct. 9, pp. 438–441; Nov. 6, pp. 567–570; Nov. 13, pp. 619–621; Nov. 20, p. 654; Dec. 4, pp. 702–703; Dec. 18,

pp. 759–762; Dec. 25, pp. 791–794). A very full description is given of the works, together with many illustrations and drawings of all plant of importance and interest.

F. J. Crolius, *Genuine Open-Hearth Iron* (Blast-Furnace and Steel Plant, Jan. 1926, vol. 14, pp. 25–36, 48). A description of the works of the Andrews Steel Company, Cincinnati, Ohio. The plant has no blast-furnace nor coking plant. Coal-firing is adopted practically throughout, pulverised fuel being used in the mill furnaces, and fine screenings under boilers. Producer gas is used exclusively in the open-hearth furnaces. The pulverised fuel plant is described in detail.

II.—*CASTING AND TREATMENT OF INGOTS.*

Pouring Ingots by a New Method (Iron Age, Jan. 14, 1926, vol. 117, pp. 128–129). An illustrated description is given of a method of pouring ingots in which a firebrick reservoir and float are used for reducing pipes and blowholes. The reservoir may be used with standard open-top moulds or with notch moulds. The reservoir rests in the notch or on top of the mould, depending on the type used, and can be set as far down in the mould as may be required. The float is supported on top of the reservoir, generally projecting about 2 inches into the reservoir. The floats are of various types, but the bottom of each is perforated with four or more holes as far from the centre as possible. The ladle nozzle is placed directly over the float, and the metal in the float drains through the holes in the float to the mould proper. In breaking the descent of the metal the float prevents the mould from being hit by a strong stream from the ladle, and also allows the escape of a considerable quantity of gases. The mould and reservoir are filled with steel until the float floats on top of the metal, thereby retaining an intense heat in the metal in the reservoir or upper portion of the ingot for a considerably longer period than is generally obtained in standard practice.

J. D. Knox, *Pouring Device Improves Yield* (Iron Trade Review, Jan. 14, 1926, vol. 78, pp. 139–142). An illustrated description of the use of a refractory float in the pouring of ingots to minimise blowholes and segregation.

J. H. Hruska, *Time of Pouring Large Ingots* (Iron Age, Nov. 12, 1925, vol. 116, pp. 1305–1306). The author gives the results of a study of the rate and temperature of pouring of large ingots. The determination of the exact relationship of both factors—time and pouring temperature—and its practical application in the making of ingot steel will probably result in an improvement of the quality of forging steel.

The Heterogeneity of Steel Ingots (Report to the Iron and Steel Institute, June 1926: this Journal, p. 39).

J. H. S. Dickenson, *A Note on the Distribution of Silicates in Steel Ingots* (Paper read before the Iron and Steel Institute, June 1926 : this Journal p. 177).

S. L. Goodale and P. H. Kutar, *Non-Metallic Inclusions in Iron and Steel* (Forging, Stamping, Heat Treating, Feb. 1926, vol. 12, pp. 68–73). The article discusses the properties of non-metallic inclusions, and various methods of identifying them.

B. Hird, *Gases Evolved from Heated Iron* (Paper read before the Institute of British Foundrymen : Foundry Trade Journal, Mar. 18, 1926, vol. 33, pp. 219–221). The author describes experiments carried out in order to determine the nature of the gas given off when solid pieces of iron are heated.

Ingot Moulds (Foundry Trade Journal, Dec. 3, 1925, vol. 32, p. 470). A brief discussion of methods for moulding and casting ingot moulds.

W. Rogers, *The "Shell" Defect in Ingot Moulds* (Foundry Trade Journal, Feb. 11, 1926, vol. 33, p. 119). The causes and prevention of shell defect are briefly discussed. The shell is a very thin layer or film of iron which appears in the corners of ingot moulds during manufacture.

FORGING AND ROLLING-MILL PRACTICE.

Reheating Furnaces.—A. Sprenger, *A Siemens Regenerative Continuous Furnace Fired with Blast-Furnace Gas* (Stahl und Eisen, 1926, vol. 46, Mar. 18, pp. 361–368). An illustrated description is given of a new continuous reheating furnace of the Siemens regenerative type, lately installed at the Differdingen Steelworks. The furnace is fired entirely with blast-furnace gas and replaces one with powdered coal firing, and one with producer-gas firing. The charge consists of blooms 6 by 6 inches, by 7 feet 6 inches long, and the furnace regularly serves three continuous mills. The output of the furnace is from 34·6 to 57 tons per hour, the heat balance records showing an efficiency up to 60 per cent., when working on cold charges.

F. G. Bell and R. Waddell, *Reheating Furnaces* (Iron and Coal Trades Review, Apr. 9, 16, 1926, vol. 112, pp. 609–610, 648–650). The authors describe the developments that have taken place at Brown Bayley's Steelworks in the design and operation of reheating furnaces. Illustrations are given of the furnaces installed, and particulars of the fuel economy effected are included.

R. J. Sarjant, *Modern Progress in Reheating Furnace Practice* (Fuel Economy Review, Mar. 1926, vol. 5, pp. 30–38). A review of the developments in the design and operation of reheating furnaces.

T. R. Speck, *A Few Observations on Furnace Design and Performance* (Drop Forger, May 1925, vol. 5, pp. 13–30). Fuels, furnace economy, recuperation and regeneration, temperature distribution, and furnace atmosphere in gas-fired heating furnaces, are discussed.

Superheating Secondary Air Supplied to Furnaces (Iron and Coal Trades Review, Oct. 23, 1925, vol. 111, p. 652). In the "A.C.M." system, in addition to the air or air and steam passed through the fire, a further supply of preheated air is delivered in such a manner as to pass over the top of the fire, causing the gases to be mixed with the superheated air. Brief particulars are given of the arrangement and principle of the system.

E. R. Posnack, *Recuperation offers Definite Savings* (Blast-Furnace and Steel Plant, Oct. 1925, vol. 13, pp. 403, 418). A description and discussion of a new tile for building recuperators. Each tile forms a standardised unit and is built up with its neighbours in a very simple fashion, but in a manner that gives a curved passage-way for the air. The construction at the same time forms a second set of straight horizontal flues at right angles to the first, and through these the hot gases pass.

E. R. Posnack, *The Development of the Recuperator* (Blast-Furnace and Steel Plant, Aug. 1925, vol. 13, pp. 327–329).

R. A. Butler, *Heating of Ingots by Electricity* (Iron and Steel Engineer, 1925, vol. 2, pp. 374–376). A two-hole electric soaking pit is described. It is fitted with four petroleum coke resistors and contains a coke breeze bottom. The power consumption for two ingots of 3 tons each is 531 kilowatt-hours, and with ideal conditions and hot ingots 100 kilowatt-hours. The advantages of this type of ingot are discussed.

E. A. Hurme, *Electric Heat-Treating Applications* (Iron and Steel Engineer, 1925, vol. 2, pp. 357–368). The author reviews the developments in the field of electric heating, including soaking pits, reheating furnaces, and heat-treatment furnaces.

C. L. Ipsen, *Determination of Furnace Efficiencies* (Forging, Stamping, Heat Treating, Mar. 1926, vol. 12, pp. 95–98).

Forging, Pressing, and Stamping.—*Universal Forging Machine* (Engineering, Dec. 18, 1925, vol. 120, pp. 768–769). This machine is built by Messrs. B. and S. Massey, Manchester. The main working part is a ram, inside which moves a constantly reciprocating piston. The motion of this latter is imparted to the ram by means of oil on both sides of it, and the ram can be raised or lowered on the piston by altering the amount of oil above or below it; this adjustment being possible while the machine is running. The heavy fly-wheel carries a clutch within itself in order to facilitate starting, as an electric motor built into the machine provides the necessary power. The machine is designed to give a maximum force of 150 tons, and, if the resistance of the work becomes greater than this, a relief valve allows oil to escape from under the piston; this protects the machine and at the same time sets the machine for further work. Stops are fitted which make it possible to forge many jobs to size without the use of gauges.

Kobert Electric Riveting and Forging Machine, Type N.C. (American Machinist (European Edition), Nov. 7, 1925, vol. 63, p. 559). This machine is adapted to the manufacture of machine parts of brass, iron, or steel that may be formed under pressure at a forging heat. The work is introduced into the machine cold, and an electric current from a transformer embodied in the machine is passed through it by electrodes, so raising the temperature to the required degree; the machine then gives one quick sharp blow, shaping the article in the water-cooled dies. The whole process is controlled by the depressing and releasing of one foot pedal.

Pneumatic Die Cushions (Machinery, Oct. 15, 1925, vol. 27, pp. 80–82). The article describes a pneumatic die cushion developed by the Marquette Tool and Manufacturing Co., Chicago. It consists of an air cylinder, and a piston having a rod to which is attached a pressure plate; the latter takes the thrust of such parts of the press tools as are used to clamp the stock during drawing and forming. A regulator on the air supply automatically maintains the pressure at the desired

amount. It is claimed that the pressure is more even on the work, and it is not necessary to have the metal run very closely to gauge to avoid wrinkling or tearing. The pneumatic die cushion has the added advantage that it converts a single-acting press into a double-acting one, and a double-acting press to triple-acting, enabling the drawing in one operation of articles usually drawn in two or three stages.

S. A. Inscoe, *Press Tools for Steel Wheels* (Machinery, Dec. 10, 1925, vol. 27, pp. 338–339). Drawings and a brief description are given of the press tools used for making wheels of steel sheet up to about 4 inches in diameter, such as are used on service wagons, trolleys, &c.

W. E. Irish, *Press-Tool Design of the American Multigraph Company* (American Machinist (European Edition), Feb. 20, 1926, vol. 64, pp. 47–49).

W. E. Irish, *Some Multiple-Operation Press Tools* (American Machinist (European Edition), Mar. 13, 1926, vol. 64, pp. 187–190).

Press for Shaping Conveyor Troughs (Engineer, Apr. 16, 1926, vol. 141, p. 450). The troughs used for conveying coal are 12 feet long by 3 feet wide, and are made of $\frac{1}{4}$-inch plate ; to press them out of cold metal by simple dies would need very great pressure, and the metal would be severely stretched at the corners of the double step. The machine illustrated uses a force of 450 tons, and by the use of special dies the action is more one of bending than of pressing. The upper female die is stationary and the lower male die is split, one part pressing the plate into the deepest recess of the opposite die and holding it, while the other part finishes the folding without any binding at the corners.

E. R. Norris, *Manganese Steel Shear Knives for Hot Work* (Blast-Furnace and Steel Plant, Apr. 1926, vol. 14, pp. 195, 200). A certain mill in the Pittsburgh district experienced considerable difficulty with its shears in 1918, owing to the high price of tungsten steels. Finally, steel, with 11 to 14 per cent. of manganese, was tried for the blades with very marked success. The blades had the further advantage that when they became worn they could be forged and reconditioned for a further period of service.

Four-Roll Type of Board Drop Hammer (Forging, Stamping, Heat Treating, Sept. 1925, vol. 11, pp. 329–332). A new type of board-drop hammer has been introduced by the Erie Foundry Co., Pa., in which four rolls are used to raise the ram, thereby distributing the friction and pressure of the rolls on the boards and making possible the use of a heavier ram.

B. Brett, *Some Remarks on Drop-Forging Equipment* (Drop Forger, Nov. 1925, vol. 5, pp. 97–121). An illustrated description of some typical forging equipment.

E. C. Abbe, *Alloy Steel Reduces Die Block Costs* (Forging, Stamping, Heat Treating, Dec. 1925, vol. 11, pp. 432–433). Die blocks made of steel with an average nickel content of 1·5 per cent. and chromium content 0·5 per cent. were found to outlast carbon steel blocks and

give greater economies. The original cost of the alloy steel dies was slightly higher than that of the carbon steel dies, as was also the cost of resinking, but the number of forgings obtained by the alloy steel dies was so greatly in excess of that made by the carbon steel dies that the actual reduction in cost of production worked out to 54·6 per cent.

Development in Drop-Forging Production (Forging, Stamping, Heat Treating, 1925, vol. 11, Oct., pp. 353–354; Nov., pp. 399–400). A brief review of the most prevalent defects in rolled steel, found by regular bar inspection. A brief description of the McQuaide-Ehn test is given. This test is used to determine whether a particular heat of steel will case-harden satisfactorily; microscopic study of the tested pieces reveals whether the heat may be expected to case-harden normally or not, according to whether they present characteristics of one or another type described in the article.

F. S. Keyes, *Hot-Stampings and their Production* (Forging, Stamping, and Heat Treating, Mar. 1926, vol. 12, pp. 105–107). The article describes the making of the dies and other tools needed for hot-stamping. The process is more complicated than cold-stamping, and does not fit in well with large production, but it is cheaper and produces articles which reproduce every contour of the die and retain their shape perfectly.

R. Barat, *Dies for Hot-Stamping* (Arts et Métiers, Nov. 1925, vol. 78, pp. 462–471). A survey of the factors involved in hot-stamping, with suggestions for improving the procedure so as to increase both the quality and quantity of the output and at the same time decrease the costs.

Manufacture of Stamped Crankshafts (American Machinist (European Edition), Oct. 24, 1925, vol. 63, p. 105E). A brief description, with line drawings, of the method of manufacture of crankshafts for motors employed in the Elswick Works of Sir W. G. Armstrong, Whitworth & Co., Ltd.

E. Shelldon, *Examples of Heavy Sheet Steel Drawing* (American Machinist (European Edition), Feb. 6, 1926, vol. 63, pp. 1035–1038). Describes the manufacture of shells from cold-rolled drawing steel of 0·109 inch gauge, as carried out at the Rockwood Sprinkler Co.'s Works at Worcester, Mass. The shells made by this process are superior to those made by the ordinary methods. The firm is also producing sleeves for the chuck of a bit-brace by the same method, using in this case hot-rolled steel 0·280 inch thick. The illustrations accompanying the article show very clearly how advantage is taken of the ability of metal to flow in order to produce a thickening just where it is needed.

W. J. Guyer, *The Production of Deep-Drawn Cylinders* (Forging, Stamping, Heat Treating, Dec. 1925, vol. 11, pp. 427–429). A description of the manufacture of deep-drawn cylinders; the example used to illustrate the paper was 6 inches in diameter, 22 inches deep, and of No. 16 gauge (0·0625 inch). The author stresses the need for care in the selection of the raw material, and explains his preference for full pickled, one-pass, cold-rolled, reannealed steel. Proper lubrication of

the punch and die, and very careful annealing and pickling between drawings, are essential. The maximum life and efficiency is obtained by the use of alloy steel for the dies; for the punches the most economical material is low-carbon machine steel or nickel steel carburised.

C. E. Hill, *The Physical Aspect of Cold-Heading and Cold-Heading Material* (Machinery, Nov. 26, 1925, vol. 27, pp. 265–269). A discussion of the types of steel suitable for cold-heading, and of the various ways in which the cold-heading should be carried out, having regard to the raw material used and the possibility or otherwise of heat treating the work. The causes of flaws and failures are also reviewed.

Cold-Heading (Machinery, 1925, vol. 27, Oct. 29, pp. 129–134; Nov. 5, pp. 161–168; Nov. 12, pp. 193–196; Nov. 19, pp. 225–228). An account of recent developments in cold-heading machines and cold-headed products. The objections formerly raised against cold-headed parts have been largely physical, but these can be overcome by the choice of the right material, by properly working it, and in some cases by suitable heat treatment. The suitability of various articles for production in this way and the various details of the processes are discussed.

The Story of Cold-Drawn Steel (Blast-Furnace and Steel Plant, Oct. 1925, vol. 13, pp. 407, 417; Mar. 1926, vol. 14, pp. 125–126). A description of the production of steel for cold-drawing is given together with notes on the plant used.

W. L. Blankenship, *A Method of Manufacturing Large Ring Forgings* (Transactions of the American Society for Steel Treating, Oct. 1925, vol. 8, pp. 474–483). The author describes and illustrates a method of forging large rings when using a forging press or steam hammer having insufficient space between the supporting column to accommodate the forging.

Notes on Heating Ingot Iron (Foundry Trade Journal, Jan. 14, 1926, vol. 33, p. 33). The correct forging and welding temperatures of ingot iron are briefly discussed.

R. L. Rolf, *Production of Automobile Front Axles* (Forging, Stamping, Heat Treating, Sept. 1925, vol. 11, pp. 293–300). The machinery employed in the manufacture of front axles and the routine laboratory tests carried out are described.

J. D. Gat, *Hard Spots in Steel Forgings* (Blast-Furnace and Steel Plant, Feb. 1926, vol. 141, pp. 74–78; Forging, Stamping, Heat Treating, Jan. 1926, vol. 12, pp. 2–7). Describes a long series of investigations to discover the cause of hard spots. These latter strongly resemble flakes of cast iron, but it was ultimately found that the picking up of cast-iron chips, to which the trouble had long been attributed, was not the real cause. The problem was finally solved when it was noticed in a certain oil-fired reheating furnace where the flames were directed slightly towards the roof to prevent them impinging on the work, that masses of soot (or rather coke, so hard was it) collected. This was very liable to fall; if it fell on a piece of steel and lay unprotected

it was soon consumed and did no great damage, but if it remained protected in some way it had time to carburise the steel locally, giving rise to a hard spot.

F. W. Rowe, *Internal Defects in Forgings* (Metal Industry, Apr. 16, 1926, vol. 28, p. 365). A forging of 3½ per cent. nickel-chrome steel had been oil-hardened and tempered. It was never used in this form, but later was turned down to a shaft of smaller size. A crack was noticed after final machining, and examination revealed a cavity over ¾-inch wide. The fault was probably due to incorrect forging practice, and while it gave an indication of the general strength of the sound metal (it had withstood oil-quenching, &c.) it emphasised the desirability of hollow boring important forgings for inspection purposes.

R. B. Wilhelm, *Failure of Billets during Forging* (Forging, Stamping, Heat Treating, Dec. 1925, vol. 11, pp. 434–435). A batch of twenty forged medium carbon steel billets were being used to make crankshafts; eighteen worked normally, but the nineteenth developed cracks in the furnace. The last was therefore examined before treating, and cracks were found to be already formed. It was supposed that the cracks developed owing to rapid cooling at the steelworks after forging the billets. The last two were of higher carbon content than the others, which would explain their greater susceptibility.

E. Cotel, *The Limit of the Hot Malleability of Steel as a Function of the Carbon Content* (Revue Universelle des Mines, Jan. 1, 1926, vol. 9, pp. 27–29). The limiting quantity of carbon in a steel, to be malleable while hot, must be determined both for rolling and for forging. It is suggested that 0·95 to 1·0 per cent. of carbon is the maximum for rolling; the malleability in the hot state with the carbon higher than this is very low and seems to disappear when the carbon reaches 1·7 per cent. The limit of carbon for forging appears to be 1·3, or, at the outside, 1·4 per cent. The alloys with carbon contents between 1·3 or 1·4 per cent. and 2·2 per cent., are neither steels nor cast irons, and have been classed as semi-steels.

I. G. Slater and T. H. Turner, *The Hardness of Carbon Steels at High Temperatures* (Paper read before the Iron and Steel Institute, June 1926: this Journal, p. 295).

A. L. Spencer, jun., *High Temperatures Hurt Rivets* (Paper read before the American Institute of Steel Construction, Nov. 1925: Iron Age, Dec. 3, 1925, vol. 116, pp. 1521–1522). The author has investigated the causes of breakage of rivets in driving. The chief cause appears to be overheating, and it is concluded that rivets heated above 1925° F. will not withstand rapid alternating compression and tension stresses.

S. A. Richardson, *Nickel Deposits on Alloy Steel Forgings* (Forging, Stamping, Heat Treating, Nov. 1925, vol. 11, pp. 407–408). The peculiar greyish, moss-like deposit sometimes seen in small patches and streaks on forgings and found to be from 75 to 90 per cent. nickel, are apparently due to overheating. The temperature required to produce

this sweating out lies, in general, above 2000° F. (1093° C.), but higher carbon nickel steels appear more susceptible to the trouble than those with less carbon. The deposit machines off quite easily, but might be expected to gum up the grinding wheel in a grinding operation. If not present in excess these patches appear to exert no harmful effect.

Forging the Flutes in Twist Drills (American Machinist (European Edition), Oct. 24, 1925, vol. 63, pp. 469–471). An illustrated account of the process devised by the New Process Twist Drill Co. The forging is done in a machine having four segmented discs, two in a horizontal plane which are shaped to match the contour of the particular size of bar of which the blanks consist, and two in a vertical plane which have rounded peripheries, and by the combined rolling action of all four parts gradually forge out straight-fluted bars. These latter are then inserted in a second machine, and by the partial rotation of a series of discs the drills are given a twisted shape. The blank is elongated about 30 per cent., and the wastage usual in the milling process is avoided.

W. P. Wood, *Bolts for Use in Power-Plant Construction* (Mechanical Engineering, mid-Nov. 1925, vol. 47, pp. 1034–1038). Discusses the lack of uniformity in the materials used in the manufacture of bolts and nuts. The advantages of steel compared with wrought iron and screw stock are described ; the best carbon content for bolts is estimated to lie between 0·10 and 0·60 per cent., the range 0·20 to 0·45 per cent. apparently yielding the best combination of tensile strength and ductility in either the heat-treated or unheat-treated condition. A tentative specification for high-temperature alloy bolting is put forward.

F. A. Stanley, *Forge Work in a Railway Shop* (American Machinist (European Edition), Feb. 13, 1926, vol. 64, pp. 5–7). A description of some of the forging practice in the Southern Pacific Railway Co.'s shops at Sacramento. Illustrations show tools for the production of hexagon and square-head bolts, tapered crown-bolts, staybolt bushings, reversible boiler checks, and wrecking-chain hooks.

R. W. Peck, *Economy in Production and the Preparation of Forgings to Ensure Grain Flow* (Drop Forger, May 1925, vol. 5, pp. 44–61).

Rolling-Mill Equipment.—T. W. Hand, *Rolling-Mills for Medium- and Small-Sized Products* (Paper read before the Cleveland Institution of Engineers : Iron and Coal Trades Review, Apr. 16, 1926, vol. 112, pp. 643–644). The author considers the developments that have been made in the design and operation of rolling-mills devoted to the production of smaller products. Particulars are given of a modern three-high spring-bar mill installed in the Sheffield district about three years ago. The double two-high mill, originally installed at Dowlais about eighty years ago, is again finding favour, particularly in the Sheffield district, where such mills appear to be employed for moderate production of wide strip and special sections generally. There is little doubt that future developments in the Middlesbrough district will lie

in the use of the continuous or semi-continuous type of mill. The purely continuous mill is almost perfectly adapted to the rolling of thin flat sections, but cannot be used for rolling shapes and certain sections requiring great accuracy. For this class of work the semi-continuous mill must be employed. Particulars of the Morgan continuous mill at the Newport Works, and recently installed mills in America, are also given. In considering the possibilities of improving British practice for small mills, the author suggests concentration on the following points: (1) Elimination of arduous manual effort, particularly where the consequences are most felt, at the earlier roughing passes. (2) The possibility of using uniformly long billets of relatively small sectional area. (3) The practicability of finishing very long lengths. (4) The possibility of maintaining uniform heat treatments from end to end of product by uniform time exposure from furnace to finishing pass. (5) Low fuel expenditure by adoption of most efficient heating furnaces. (6) Low-power consumption due to smallest practicable diameter of rolls for given product. (7) Minimum labour costs by adoption of mechanical devices.

J. Horton, *Completes Large Universal Plate Mill in Great Britain* (Iron Trade Review, Dec. 31, 1925, vol. 77, pp. 1643–1646, 1656). An illustrated description of the new plate mill recently placed in operation at the Moss End Works of Stewarts and Lloyds, Ltd.

Works Modernisation (Electrician, Nov. 27, 1925, vol. 95, pp. 623–624). A description of the electrical gear introduced into the hoop and strip mills and a rod mill in the Middlesbrough works of Messrs. Richard Hill & Co., when the mills were changed over from steam to electric drive. An account of the actual change-over is given in brief.

Steelworks Electrification (Electrician, Nov. 27, 1925, vol. 95, pp. 625–626). A description of the electric reversing drive built by the English Electric Co. for the 30-inch rail and section mill at the Dowlais works of Messrs. Guest, Keen and Nettlefolds.

New 34-Inch Universal Plate Mill (Electrician, Nov. 27, 1925, vol. 95, pp. 621–622). Description of the electrical gear used on the largest universal plate mill in Great Britain. It has been constructed for use in the works of Messrs. Stewart and Lloyds at Glasgow. (See also this Journal, 1925, No. II. p. 449.)

R. C. D. Fell, *Rolling-Mill Machinery* (The Association of Engineering and Shipbuilding Draughtsmen, Session 1925–26). The author describes the salient features of rolling-mill practice for the production of blooms, billets, plates, rails, sections, sleepers, bars, rods, &c. The lay-out of the different mills and their auxiliary equipment is also described and illustrated.

New Lackawanna Rolling-Mills (Iron Age, Feb. 11, 1926, vol. 117, pp. 404–410). Illustrated particulars are given of the lay-out and equipment of the new structural mills and the alterations made to the blooming-mill at the Lackawanna plant of the Bethlehem Steel Corporation.

Two new structural mills have been put down; the first consists of one two-high stand of reversing 35-inch rolls and three stands of 28-inch rolls, the first two of which are three-high, while the finishing stand is two-high. The 28-inch stands are all in line and are driven by a single motor. The second mill consists of ten stands of two-high rolls on the continuous principle, five stands of which have 18-inch rolls and the others 14-inch rolls. The mills are electrically driven.

R. A. Fiske, *Blooming-Mill has Heavy Drive* (Iron Age, Oct. 15, 1925, vol. 116, pp. 1019–1023). Illustrated particulars are given of the new single-unit reversing motor for driving the 40-inch blooming-mill at the Wisconsin Steelworks, South Chicago. The mill has a capacity of 70,000 tons a month. Three-phase 60-cycle current reaches the mill motor switchboard at a voltage of 2300, and is fed directly to a motor generator set and exciters. The former consists of two d.c. generators, each rated at 3000 kilowatts and 700 volts, a 14-foot fly-wheel and a 4000 horse-power induction motor, all mounted on a common shaft. The speed of this unit is 352 revolutions per minute. The rated temperature rise of the motor is 50° C. and that of the generators 40° C. The motor driving the mill is rated at 7000 horse-power, 700 volts, 50 to 120 revolutions per minute, with a temperature rise of 50° C. The exciter set is a three-piece unit consisting of a 130 horse-power constant-speed induction motor, direct connected to a 70 kilowatt constant-potential 250-volt d.c. generator, and a 15 kilowatt variable-potential 240 volt d.c. generator. This unit operates at a speed of 685 revolutions per minute. A slip regulator is also provided. An illustration is included of the lay-out of the mill.

Ford Merchant Mill in Operation (Iron Age, Jan. 21, 1926, vol. 117, pp. 197–201). The new 14-inch continuous merchant mill recently placed in operation at the River Rouge plant, Detroit, is described and illustrated. The mill is of the Morgan staggered duo type. It contains six 18-inch continuous roughing stands and four staggered 14-inch finishing stands, all two-high. The mill is served by two 16 × 40 feet continuous furnaces fired with oil fuel, although provision has been made for the use of coke-oven gas. Both furnaces are side-charged. Motor-driven pushers advance the billets through the heating chamber, and they pass by gravity sideways through the discharge end of the furnace. All equipment is electrically driven.

J. D. Knox, *Six-Roll Cluster-Type Cold Mill* (Iron Trade Review, Apr. 15, 1926, vol. 78, pp. 989–991, 1002). A new type of mill for the production of high-grade sheets is described and illustrated. By the use of this mill a number of steps in the manufacture of sheets are eliminated. Six rolls are employed. The two top and two bottom rolls are known as the backing-up rolls, while the pair of smaller rolls between the backing-up rolls are known as the working rolls.

The High-Speed Cold Rolling-Mill (Engineer, Dec. 25, 1925, vol. 140, pp. 688–691). The author compares the rolling speeds adopted in Great Britain and Europe with those in the United States

and indicates the reasons for the difference ; he is, however, of opinion that the arguments against high-speed rolling are not based on facts. He describes, with illustrations, a new mill recently built by Messrs. W. H. A. Robertson & Co., Ltd., and erected in a large Continental works for brass rolling, and gives details of trials carried out on it. It has rolls of forged chrome alloy steel, hardened to 95–100 degrees scleroscope hardness, 11·8 inches in diameter, and faces 13·8 inches wide; the rolls made 62 revolutions per minute, giving a rolling speed of 192 feet per minute, the driving motor generating 80 horse-power. The mill was guaranteed to reduce strip 6·3 inches wide from 0·059 inch to 0·0315 inch thick in two passes; trials proved it to be capable of heavier reductions on a greater width of metal than this.

W. Lester, *Discourse on Draught for Rolling-Mill Furnaces* (Blast-Furnace and Steel Plant, Oct. 1925, vol. 13, pp. 404, 417). The author strongly advocates hot draught, on account of the ill-effects arising from the admission of cold air to the furnaces. A simple pre-heater for the purpose is described.

Rolling of Steel.—W. Tafel, *The Theory and Practice of Rolling Steel* (Iron Trade Review, 1925, vol. 77, Oct. 15, pp. 964–966; Oct. 22, pp. 1033–1036 ; Nov. 5, pp. 1143–1146 ; Nov. 19, pp. 1277–1280 ; Dec. 3, pp. 1404–1406, 1434 ; Dec. 17, pp. 1530–1533 ; Dec. 31, pp. 1651–1655 ; 1926, vol. 78, Jan. 21, pp. 209–213 ; Feb. 4, pp. 331–335 ; Feb. 18, pp. 457–460 ; Mar. 4, pp. 570–572, 575 ; Mar. 18, pp. 697–699 ; Apr. 1, pp. 864–866 ; Apr. 15, pp. 995–998 ; Apr. 29, pp. 1119–1122). This series of articles, when completed, will form an English translation of the author's book on the principle and practice of rolling iron and steel.

L. Rothera, *Speed Control in Relation to Modern Rolling-Mill Drives* (Journal of the West of Scotland Iron and Steel Institute, Session 1925–1926, vol. 33, pp. 24–30). The various methods of obtaining variable speed are discussed. Four such methods have been developed and put into practice, namely, the Kramer and Scherbius systems, the cascade drive, and frequency-changing device.

J. S. Caswell, *The Forces Set Up in the Operation of Sheet and Tinplate Mills* (Proceedings of the South Wales Institute of Engineers, 1926, vol. 42, pp. 119–196). The author considers the forces set up in sheet and tinplate mills during their normal operation. These forces are momentary, and they fluctuate over a wide range. Their magnitude depends on numerous factors, which are considered, and as far as possible their values are expressed in appropriate formulæ and numerical values.

H. Harris, *Spalling of Sheet and Tinplate Rolls* (Blast-Furnace and Steel Plant, Aug. 1925, vol. 13, pp. 334–335). The spalling of the rolls is attributed to careless use of the cooling water. The spalling of hard-chilled sheet or tinplate rolls is caused by the water used to cool the roll necks, seeping out of the top roll necks and striking the

hot-chilled surface of the lower rolls. Cleaning out the hard hot neck grease from the top neck allows the water to drop directly on to the neck of the lower roll and stops the trouble. Plate mills often spall because the rolls are allowed to get too hot before being cooled again with water.

W. Dawson, *Reasons for Breakage of Mill Rolls* (Iron Age, Dec. 10, 1925, vol. 116, pp. 1587–1588). Ten common causes of roll breakage are outlined.

Scraping Defects from Hot Steel (Iron Age, Nov. 19, 1925, vol. 116, pp. 1375–1377). An illustrated description is given of an installation of a billet scraper on a continuous mill for removing surface flaws during rolling. For billets the scraping device consists of one or two units per billet mill, each unit consisting of two vertical and two horizontal acting knives. The cylinders actuating the knives are automatically controlled by air. The power required for driving the billet through the knives is small and is supplied by the rolls. For sheet bars the device consists of two sets of vertical-acting knives, one preceding the other by about 9 inches. One set of knives is used for scraping the sides of the bar. The knives are capable of removing fins.

F. L. Estep, *Removing Scale Mechanically* (Blast-Furnace and Steel Plant, Dec. 1925, vol. 13, pp. 476–477; Forging, Stamping, Heat Treating, Dec. 1925, vol. 11, pp. 425–426). Description of an apparatus for scraping off scale, slivers, scabs, &c., from billets during rolling.

Large Roll-Grinding Machine (Iron Age, Dec. 31, 1925, vol. 116, p. 1805). Brief particulars are given of the roll-grinding machine installed at the Munhall plant of the Carnegie Steel Co. Its capacity is for rolls 54 inches in diameter and 21 feet in length. It is one of the largest machines of its kind ever built.

Roll-Wobbler Planer (Iron Age, Dec. 31, 1925, vol. 116, p. 1807). A brief description is given of a heavy travelling head roll wobbler planing machine which accommodates rolls up to 56 inches in diameter.

Tube Manufacture.—P. Cebrat, *Seamless Steel Tube Manufacture* (Iron Age, Mar. 4, 1926, vol. 117, pp. 619–620). The Pilger process is the most successful method of producing seamless tubes from about 6 to 16 inches diameter. It also has distinct advantages for sizes from 6 down to 2 inches. Since, for mechanical reasons, it is not possible to push the entire length of the pierced blank through the Pilger rolls, a bell-shaped end remains on one end of the tube. In a number of cases this bell is retained and formed in special presses into a shape similar to the bell end of cast iron pipes, and used for water and gas lines. Most of the German and other Continental tube mills are cramped for space, consequently the movement of material is awkward and uneconomical. As a rule, all German Pilger mills use a bottom-cast ingot, slightly tapered. Ingots below about 10 to 12 inches diameter and down to the limit of about 5 inches are usually cast for two or three lengths of tube and are broken in hydraulic presses.

For smaller tubes hot-sawn rounds are used. Push-bench plants, piercing by hydraulic press, use a rolled square billet. At one German plant the practice is to turn the skin off the ingot in a shaft lathe. A special lathe, devised by H. Becker & Co., Düsseldorf, is finding great favour for turning the rolls of Pilger mills.

P. Cebrat, *Seamless Tube Mills Analysed* (Iron Age, Feb. 18, 1926, vol. 117, pp. 473–476). The author discusses the limitations and advantages of the different processes for the production of seamless tubes. The principal methods in use are as follows :

I. Piercing mill and Pilger mill (Mannesmann process).
II. Piercing press and push bench (Ehrhardt and Wellman-Peters process).
III. Piercing press and draw-bench for large diameter tubes.
IV. Piercing mill and continuous mill.
V. Piercing mill (Stiefel process) and two-high (plug) mill (Swedish process).
VI. Pre-piercing and piercing press and two-high mill.
VII. Piercing press (Ehrhardt) and two-high mill.
VIII. Piercing mill and two-high mill.
IX. Piercing press, draw-bench, and special rolling-mill (Ehrhardt system) for hollow bodies of large diameter.

The diameters, normal lengths, and wall thicknesses that can be produced successfully by the different processes are shown.

E. C. Kreutzberg, *First Automatic Pilger Mill in U.S. now Operating* (Iron Trade Review, Mar. 4, 1926, vol. 78, pp. 567–568). Illustrated particulars are given of the Pilger mill in operation at the plant of the Delaware Seamless Tube Co., Auburn, Pennsylvania.

Seamless Tubes by Mechanical Mill (Iron Age, Mar. 11, 1926, vol. 117, pp. 681–685). The first automatic Pilger mill to be put into operation in the United States is described and illustrated. It is installed at the plant of the Delaware Seamless Tube Co., Auburn, Pa. Solid round billets are first formed into rough tubes in a Mannesmann piercing mill, and then finished on a mandrel in the Pilger mill, where the wall thickness is reduced, at the same time improving the smoothness and finish of the surface. The direction of rotation of the Pilger rolls is opposite to that in the ordinary rolling process, and the rolls are so designed that the tube in its passage through the mill is given a forging or kneading action. Advancement of the mandrel carrying the tube is produced by hydraulic pressure.

C. Wolff, *The Use of Steel Treated with Silicon for the Production of Seamless Tubes in Skew Rolls and Pilger Rolls* (Stahl und Eisen, Nov. 26, 1925, pp. 1958–1961). By means of illustrations of ingot billet and tube sections made from steel treated with silicon and from steel that has not been so treated, the author demonstrates the fact that the silicon-treated steel is much the more suitable of the two for the rolling and drawing of seamless tubes.

E. F. Ross, *Making Seamless Steel Tubes by Improved Processes* (Iron Trade Review, Oct. 29, 1925, vol. 77, pp. 1079–1083, 1091). An illustrated description of the equipment and methods employed at the works of Howell & Co., Ltd., Sheffield, where seamless tubes are produced by the Wellman-Peters process. The article also contains a description of the manufacture of seamless tubes by the Pilger process.

Works of the Bromford Tube Co., Ltd. (Iron and Coal Trades Review, Apr. 2, 1926, vol. 112, p. 568). Brief particulars are given of the lay-out and equipment of these works at Erdington. Weldless tubes are produced in a Pilger mill, the blanks being pierced by the Stiefel process.

Machine for Slitting and Coiling Tubes (Iron Age, Nov. 12, 1925, vol. 116, pp. 1317–1318). A description is given of a machine in operation at the plant of the Niagara Electrolytic Iron Co., Niagara Falls. In the electrolytic process the iron is recovered in tubes formed upon a mandrel. If the iron is not required for use in tubular form, it is cut into strips and coiled upon the special machine described.

Wire-Drawing.—K. B. Lewis, *Increasing Wire-Drawing Speed* (Iron Age, Oct. 15, 1925, vol. 116, pp. 1028–1029, 1084). The author discusses the relation between drawing speed and the cost of production. The advantages of the continuous drawing machine are pointed out.

Application of Electric Motor Drives to Wire-Drawing Machinery (Iron and Coal Trades Review, Jan. 1, 1926, vol. 112, p. 29). Illustrated particulars are given of the use of electric motors for driving wire-drawing plant. At the Riverside Works, of Messrs. Boulton and Paul, Norwich, the machines are driven by 440-volt B.-T.-H. direct-current motors of 20 and 10 horse-power. At the Cardiff Works of the Excelsior Wire Rope Co., slip-ring induction motors are employed, and 440-volt, 25-cycle, three-phase current is used. At the works of Frederick Smith & Co., Ltd., Halifax, B.-T.-H. motors of various sizes are in operation.

FURTHER TREATMENT OF IRON AND STEEL.

Cementation and Case-Hardening.—F. W. Rowe, *Modern Case-Hardening Practice* (Automobile Engineer, 1925, vol. 15; Nov., pp. 426–428; Dec., pp. 467–469). The author discusses the whole subject of case-hardening. He touches on the selection of a suitable steel and of the carburiser, enumerating the qualities that are to be looked for and the usual faults which may be found in these substances. An account of carburising practice follows, and methods are detailed for the partial case-hardening of objects. The author is not in favour of using asbestos and other paints for this purpose; a dense electro-deposit of copper 0·003 inch thick on the parts to remain soft is satisfactory, and an equally good result is obtained by clamping a sheet of pure copper on the part, provided the space between the copper and the steel does not exceed $\frac{1}{64}$ inch. Brief notes are given on the heat treatment of the hardened articles, together with the modifications required for alloy case-hardening; mention is made of low-temperature tempering.

W. E. Day, jun., *Carburisation by Solid Cements* (Transactions of the American Society for Steel Treating, Feb. 1926, vol. 9, pp. 240–258). The author has studied the carburising process when using solid compounds, and discusses those points which have the greatest bearing on the commercial application of the process. The production of carburising gases from the cement and their reaction on the steel are dealt with, also a study is made of the mechanism through which the carbon travels from the surface of the metal inward. Photomicrographs and curves are included, showing the results of the investigation.

J. Laissus, *Contribution to the Study of Metallic Cementations. The Cementation of Iron Alloys by Chromium* (Revue de Métallurgie, Mémoires, Mar. 1926, vol. 23, pp. 155–178). The author has studied the principal factors and the theory governing the cementation of iron alloys by chromium, by means of a micrographic examination of the diffusion of chromium into iron, and he has examined the properties of these alloys after "chromisation." Finely divided ferro-chrome was used as the cementation medium, and this and the specimens were enclosed in iron tubes in such a manner that oxidation was avoided without the passage of hydrogen through the furnace. The effect of the time and temperature of the cementation process and of the compositions of the iron alloys and of the cementation medium were studied, and besides recording his experimental results the author draws the following general

conclusions. The best results appear to be obtained by the use of a high temperature. Both the alloy and the cementation material should be low in carbon. Materials chromised at high temperatures (1000° to 1200° C.) will take a fine polish, are more resistant to oxidation at high temperatures than untreated products, and strongly resist attack by nitric acid.

J. Laissus, *Cementation of Ferrous Alloys by Tungsten* (Comptes Rendus, 1926, vol. 182, pp. 465–467). Finely powdered ferro-tungsten was used as a cementing agent for electrolytic iron and for steels with 0·15 to 0·8 per cent. carbon. The cementation zone decreased in thickness with increase in the carbon content of the steel. A bright outer layer was formed consisting probably of tungsten carbide. The cemented steels showed resistance to corrosion by water and sulphuric and hydrochloric acids, but were rapidly attacked by nitric acid. The temperature of cementation was 800° to 1100° C.

A. Fry, *The Krupp Process of Case-Hardening with Nitrogen* (Kruppsche Monatshefte, Feb. 1926, vol. 7, pp. 17–24). Parts to be case-hardened by nitrogenation must be completely machined and finished off before case-hardening. The distortion or deformation is so very slight that subsequent grinding is generally unnecessary. The parts are exposed to nitrogen in a nascent state and at a temperature of 580°, the period of exposure being dependent on the depth of case required. On completion of the operation the surfaces show exactly the same state of finish as at the start and are entirely uninjured. They receive a grey or coloured appearance which can readily be polished off, leaving a bright highly polished surface. Numerous illustrations of articles with surfaces rendered glass-hard by nitrogenation are shown. The process does not claim to replace the ordinary one of case-hardening by carburisation, by which a greater depth of case can always be obtained, but it proves of great utility for the case-hardening of small parts not subjected to extreme pressure and for which a glass-hard surface is required. Complicated parts can be more successfully treated by the nitrogen process than by carburising.

P. W. Hay, *Recuperation in Carbonising Steel* (Forging, Stamping, Heat Treating, Nov. 1925, vol. 11, pp. 403–404). The case-hardening furnaces of the Buda Co., of Harvey, Ill., are fired with low-pressure gas. The burnt gases on leaving the furnaces pass through recuperators and these are used to preheat the air necessary for the combustion of the fuel gas. The air is supplied at a pressure of 18 to 20 ozs., and the saving in gas by the use of the recuperators is approximately 15 per cent.

E. H. Stilwill, *Copper "Migration" in Carburising* (Transactions of the American Society for Steel Treating, Feb. 1926, vol. 9, pp. 323–325). Experiments carried out by the author to investigate the non-uniform carburisation of copper-plated automobile camshafts showed that the trouble was due to the presence of lead in the carburising compound. The gears were tested for heir bearing qualities in red-lead and linseed-oil, and some of the lead remained on the gears during car-

burisation, contaminating the compound. This resulted in areas protected by the copper plating becoming hardened, and those areas which were desired to be hardened remained soft. The trouble was overcome by washing the gears in painter's spirit or gasolene before carburising. Two methods of selective carburising are outlined.

E. G. Mahin, R. C. Spencer, and C. R. Hayner, *Effect of Other Elements upon Migration of Carbon in Steel* (Proceedings of the Indiana Academy of Sciences, 1925, vol. 34, pp. 177–180). This paper is introductory to an extensive investigation of the influence of other elements on the rate of carburisation and migration of carbon in steel.

Pyrometry.—J. L. Haughton, *Pyrometry* (Metallurgist, 1925; Nov. 27, pp. 162–165; Dec. 25, pp. 179–181). A review of more modern methods of measuring and recording high temperatures. Brief reference is made to the mercury thermometer and the modifications that have been introduced to permit of its use up to about 700° C.; also to Northrup's variation in which molten tin was to be used in a graphite tube and bulb in order to read up to as high as 1800° C. Platinum resistance, total radiation, and optical pyrometers are dealt with more fully. The various types and their method of use are described, and their advantages, disadvantages and sources of error are pointed out. Among the instruments discussed are the following: The Wheatstone bridge and the Callendar and Griffiths automatic recording bridge, for use with platinum resistance pyrometers; the millivoltmeter, the thread recorder, and the Leeds and Northrup potentiometric recorder, working with thermocouples; the Féry total radiation pyrometer; the Wanner, and Griffiths and Scholefield optical pyrometers.

Notes on the Measurement of High Temperatures (Stahl und Eisen, Nov. 5, 1925, pp. 1850–1854). Advice concerning the use of various types of pyrometers is presented. Thermo elements are suitable for temperatures up to 1200° and have given dependable readings up to 1600°, but as they are highly sensitive to hydrogen and carbon monoxide they require protection and must be used in gas-tight tubes. The disadvantage of most thermo-electric measurements is that they register neither the wall temperature nor the gas temperature in a furnace, but some intermediate value the exact relation of which to those actual temperatures is difficult to establish. Optical pyrometers are therefore best for wall temperatures, and suction pyrometers for gas temperatures. The conditions under which these types can be used with good effect are described.

D. H. Lee-Bird, *Pyrometry for the Drop Forger* (Drop Forger, Aug. 1925, vol. 5, pp. 36–49).

New System of Numbering for Seger Cones (Tonindustrie Zeitung, 1925, vol. 49, p. 1234; Stahl und Eisen, Jan. 21, 1926, vol. 46, pp. 83–84). Proposals have been put forward some time ago to change the present system of numbering Seger cones, of which there are 72, and to adopt for each cone a number corresponding to one-tenth of its

fusion point in degrees C. By this means it is thought it will be easier to memorise the numbers of the cones and the temperatures which each is intended to measure. Thus cone 26, which melts at about 1580°, would receive the number 158. In cases where the last digit is not a nought but a 5, the 5 would be treated as a nought. In France and other Continental countries the new system has been largely adopted.

Heat-Treatment Plant and Equipment.—W. Trinks, *Industrial Furnaces* (Mechanical Engineering, mid-Nov. 1925, vol. 47, pp. 1065–1071). A comparison of the conditions existing in boiler and industrial furnaces and of the fuels to be used in industrial furnaces. Fuel-fired and electrically heated furnaces, their temperature control and thermal efficiency, are discussed. Several special types of furnace, both fuel-fired and electrical, used for particular kinds of work, are illustrated.

Radiant Heat Furnaces (Engineering, Jan. 22, 1926, vol. 121, pp. 106–108). The furnaces described are all heated on the principle of surface combustion. A flat brick or tile of highly refractory material is pierced with small holes about $\frac{1}{8}$ inch in diameter, which run into larger holes of about $\frac{1}{2}$ inch in diameter near the front surface. Gas and air, the latter usually preheated, are supplied to the backs of the bricks held in special holders, and the combustible mixture burns flamelessly on the inner surface of the larger holes, so raising the temperature of the bricks. The contents of the furnace are, of course, heated by radiation. Any clean gas can be used, including town gas, Mond gas, blast-furnace gas, and coke-oven gas. These furnaces are known as Krupp radiant-brick furnaces.

H. Nathusius, *American Electric Annealing Furnaces and their Advantages over Fuel-Heated Furnaces* (Stahl und Eisen, Dec. 24, 1925, vol. 45, pp. 2113–2117). The author points out the present superiority of the American industry in building and running electric furnaces. He describes some of the furnaces in use and the principles on which they depend. Among the technical and economic advantages which he ascribes to electric furnaces are—the improvement of the quality of the products; the reduction, if not total prevention, of rejects due to bad annealing; the decrease of waste and of cost of repairs; the increase of output, and other advantages, such as improved conditions in the shop owing to the presence of less smoke and heat radiation.

Modern Batch Annealing Furnaces (Iron and Coal Trades Review, Nov. 13, 1925, vol. 111, p. 785). The annealing furnaces for tinplate and black plate in operation at the Morfa Tinplate Works, Llanelly, are described. There are two gas-fired furnaces each with a capacity of about 30 tons, or 600 basis boxes per charge. The furnaces are of the single-ended type, the bogies being charged and withdrawn from the same end. The gas from the mains is delivered to each furnace at two points, a gas flue being provided in each side wall. Each flue supplies five gas ports, situated at the base of a vertical combustion shaft.

Preheated secondary air is also supplied at the same point, so that the admixture of gas and air and initial combustion occurs before the discharge of the gas into the annealing chamber. For tinplate annealing the gases are discharged at a high point and the furnace works on the down-draft principle, the gases being drawn down through small port-holes in the bed of the bogie. From these port-holes the waste gas is withdrawn across a clearance space between the bogie and the side wall of the furnace, and immediately above the sand seal. This method of withdrawing waste gases prevents the seepage of air into the furnace. The waste gases are passed through a small continuous recuperator, a separate recuperator being provided below each combustion shaft.

Carbonising and Hardening Steel (Iron Age, Mar. 18, 1926, vol. 117, pp. 764–765). Continuous electric furnaces for the carburising and hardening of automobile parts, in operation at the plant of the Hudson Motor Car Co., Detroit, are described and illustrated. The carburising furnaces are of the counterflow pusher type, the work moving in both directions. The furnace chamber is divided into five different temperature zones. In the hardening furnace the work is carried through on an endless conveyor, from which it drops through a chute into another conveyor submerged in an oil-quenching tank. The discharge end of the chute is below the surface of the oil, thus preventing the admission of air through the chute into the furnace chamber.

Gears Heat-Treated Electrically (Iron Age, Feb. 11, 1926, vol. 117, pp. 401–402). An illustrated description is given of new types of continuous automatic electric normalising and hardening furnaces for the heat treatment of gears. They are in operation at the plant of the General Motors Corporation, Detroit. The outstanding feature of the normalising furnace is that the work enters and is discharged from each end. There are four conveyor tracks, two inside ones carrying the work in one direction and the two outside tracks in the opposite direction. The cold-work entering at each end absorbs heat from the hot-work leaving the furnace, so that the former is preheated and the latter partially cooled. The furnace is 26 feet long, with a heating chamber 5 feet 3 inches wide and 1 foot high. The hardening furnace is of the vertical pusher type. The gears move through the furnace in the form of a vertical stack. The mechanism consists of a slide under the hearth, and a plunger which raises it into its position at the bottom of the stack. When a gear is raised it is held in place by three notches, and the plunger returns for another gear. The slide which carries the work to the plunger is operated by a cam and gear. The furnace when loaded holds sixty gears, and its rated output is one a minute.

Automatic Heat-Treating of Steel (Iron and Coal Trades Review, Mar. 5, 1926, vol. 112, p. 385). Brief particulars are given of a method in use on the Rand for heat-treating rock-drill steel automatically. The installation consists of (1) an oil-fired furnace whose temperature is controlled automatically by pyrometers and whose atmosphere is reducing; (2) a quenching bath containing, at the tempering point, a

bubble or fountain of water over which each bit is held for a definite time; (3) speed control, whereby the times of heating, tempering, and quenching are varied together, depending on the size of the bit treated.

C. M. Walter, *Some of the Most Recent Types of Furnaces for Heat-Treatment Operations* (Drop Forger, Feb. 1926, vol. 5, pp. 178–214). The author deals with furnace plant suitable for the heat treatment of forgings.

W. Krämer, *Annealing Boxes for Thin Sheets* (Stahl und Eisen, Jan. 14, 1926, vol. 46, pp. 46–47). Various types of annealing boxes are shown, designed with a view to overcoming the difficulties due to distortion.

C. T. Willard, *A Mechanically Equipped Hardening Room* (American Machinist (European Edition), Oct. 10, 1925, vol. 63, pp. 375–379). An illustrated description of the hardening plant in use at the Elizabethport, N.J., plant of the Singer Manufacturing Company. The parts to be hardened vary from very minute articles up to objects such as 1½-inch shafts, 36 inches long. An interesting feature is the card file containing complete hardening specifications for each of over 20,000 items. When a part or batch of parts arrives for hardening, a work ticket is made out giving details of the procedure to be followed; this ticket follows the work and serves as a perpetual inventory card.

E. L. Wood, *A Modern Heat-Treating Department* (Forging, Stamping, Heat Treating, Sept. 1925, vol. 11, pp. 290–292). A description, with illustrations, of the heat-treating plant of the Geometric Tool Co., New Haven, Conn. In the high heat furnace a floor tile of carborundum has been found to be an improvement; the 4-pot high-speed hardening furnace has four chambers, a semi-muffle preheat, a salt preheat, a salt high heat, and a salt quench, and the burners are arranged to fire the high heat chambers, the exhaust gases passing then to the two preheaters, so effecting much economy. The linings of these chambers and their ducts are made of carborundum cement, and the high heat salt bath is contained in a carborundum-lined steel pot. The high-speed drawing furnaces are worked in conjunction with preheaters in the same way, and here also salt baths are used as the actual heating medium in most cases, although this method is not without objection. Similar furnaces are used for carbon steel hardening and cyaniding. Great attention is paid to pyrometric control.

J. Younger, *Where Should Heat-Treating be Done?* (American Machinist (European Edition), Oct. 10, 1925, vol. 63, pp. 389–391). The Ajax Motors Company have found that the inclusion of the electric furnace for heat treatment has several advantages. For small articles like gears there is no need to await the accumulation of a number before starting heat treating a batch, because small furnaces can be used which handle the parts almost one at a time. The company make their motor-car gears of medium carbon alloy steel, with 0·40 to 0·50 per cent. carbon and 3·5 per cent. nickel. They are heated in Leeds-Northrup electric furnaces to 1450° F. and immersed for eight seconds in

a cyanide bath before quenching in oil. They are then raised to 450° F. in a nitrite bath, and finally thoroughly cleaned in boiling water. The scleroscope hardness attained is 70, and the gears have a hard skin capable of resisting clashing and ordinary wear.

C. B. Bellis, *Heat-Treating Methods and Apparatus* (Transactions of the American Society for Steel Treating, Dec. 1925, vol. 8, pp. 837–850). The author discusses the technique of heat-treating methods and apparatus. A description is given of an equipment for heating tools by means of the lead bath. The author also discusses the use of the electric rotary furnace for small parts, the electric salt bath for rock-drills, and the heat treatment of wrist pins. The heat treatment of dies is also considered.

S. Tour, *Design and Operation of Furnaces for Salt Baths* (Transactions of the American Society for Steel Treating, Apr. 1926, vol. 9, pp. 553–570). The paper points out the need for proper furnace design and operation for the heat treatment of metals in salt baths. The method of heating, the distribution and radiation of heat, and the elimination of overheating are vital factors in this type of furnace. The general requirements regarding salt bath furnaces are enumerated, and illustrations of furnaces are given showing the way in which these requirements may be met.

Heating Steel by the Salt Bath Method (Iron Trade Review, Nov. 5, 1925, vol. 77, pp. 1148–1149, 1151). Several types of salt bath furnaces for the heat treatment of steel parts are illustrated and described.

Annealing Wire in Salt Bath (Iron Age, Apr. 1, 1926, vol. 117, p. 928). Brief particulars are given of a method of annealing wire in a salt bath. The method known as the Lavite process is in successful operation in America. A special salt is employed of which no particulars are included. It is claimed that this method gives uniformity in heating and a better surface to the wire.

L. E. Crease, *The Protection of Thermocouples in Electrically Heated Salt Baths* (American Machinist (European Edition), Jan. 2, 1926, vol. 63, p. 864). Fused salt baths, such as barium chloride, attack mild steel sheaths used on thermocouples. Nickel-chromium alloy is satisfactory in every way except that after three or four days' continuous running at 850° C. in such a bath it becomes porous. By using a double sheath, of mild steel inside and nickel-chromium alloy outside, satisfac tory results were obtained.

Heat Treatment of Iron and Steel.—W. Rosenhain, R. G. Batson, N. P. Tucker, *The Effect of Mass in the Heat Treatment of Nickel Steel* (Paper read before the Iron and Steel Institute, June 1926: Publication deferred pending further experiments.

A. R. Page, *The Hardening and Tempering of High-Speed Steel* (Paper read before the Iron and Steel Institute, June 1926 : this Journal, p. 307).

H. Scott, *Origin of Quenching Cracks* (United States Bureau of

Standards, 1925, Scientific Paper 513). During an investigation of the effect of heat treatment on certain properties of tool steel, a large number of failures from cracking were observed when 1-inch diameter cylinders made from deep-hardening steels were quenched in oil, even from fairly low temperatures, but not when quenched in water. Examination of the cracked specimens showed that failure was due to tensional stress at the surface. The axial stress at the surface after quenching in water was found by experiment to be compressional and high. It was concluded therefrom that hardened steel, like glass, is highly resistant to compressional stress but not to tensional stress. Conditions producing cracks in a particular oil-hardened steel were determined experimentally. It is shown that cracks are produced by permanent stress, which reaches a maximum value at ordinary temperatures. Permanent tensional stress at the surface can be produced by cooling only when the steel is plastically deformed while the coefficient of expansion is negative. This condition was demonstrated from an experimental study of the expansion of steel during hardening. From an analysis of the temperature distribution during quenching expressions were derived showing the relations between the major variables of quenching and the internal stress. These relations are in agreement with the experimental results, and suggest practical expedients for the control of internal stress.

H. J. French and O. Z. Klopsch, *Initial Temperature and Mass Effects in Quenching* (Transactions of the American Society for Steel Treating, Jan. 1926, vol. 9, pp. 33–74, 142–143; United States Bureau of Standards, 1925, Technologic Paper No. 295; abstract in Journal of the Iron and Steel Institute, 1925, No. II. p. 473).

J. H. Andrew, M. S. Fisher, and J. M. Robertson, *Specific Volume Determinations of Carbon and Chromium Steels* (Journal of the Royal Technical College, Glasgow, Dec. 1925, No. 2, pp. 70–78). This paper is concerned with the measurement of the specific volume of a series of plain carbon and chromium-carbon steels. Determinations were made with the steels in the hardened or quenched condition, and in the quenched and tempered condition. The change in specific volume with rise in tempering temperature was also measured, and the effect of tempering temperatures is discussed.

L. Aisenstein and E. Decherf, *Study of the Overheating of Steel* (Revue Universelle des Mines, Dec. 15, 1925, vol. 8, pp. 330–346). Details are given of a research to determine the effect of overheating on the tensile strength, elastic limit, elongation, reduction of area, and other properties of steels. The two temperatures 1000° and 1200° C. were chosen for overheating, and the samples tested included soft, medium, and hard carbon steels, 2 per cent. and 5 per cent. nickel steels, and soft and medium hard chrome-nickel steels. The possibility of reconditioning the overheated metal by a simple heat treatment was also investigated, the economic aspect in this respect being kept in view. It was found that the higher the carbon content the greater

the tensile strength and hardness became on overheating, while the other properties, elongation, reduction of cross-section, &c., diminished, the decrease of these latter becoming more marked as the temperature of overheating rose. Annealing for one hour was found to bring back the properties of those steels overheated at 1000° C.—in fact, the elongation and resilience were improved. Similar annealing of the steels overheated at 1200° C. conferred only inferior properties on the samples except as regards the tensile strength. The comparisons were made against annealed specimens.

H. B. Knowlton, *Facts and Principles concerning Steel and Heat Treatment* (Transactions of the American Society for Steel Treating, Oct. 1925, vol. 8, pp. 484–506). The author deals with the annealing of steel. The term " annealing " is loosely used to mean any one of a number of treatments which attempt to relieve strains and to soften steel. True annealing involves heating the steel to above the critical point, followed by slow cooling. The other class of treatments consist in heating the steel to below the critical point, followed by any rate of cooling. The American Society for Steel Treating has proposed the term " loneal " to apply to these treatments. Although both treatments soften the steel and relieve strains, the results produced are quite different. The results produced by both treatments are discussed by the author.

H. B. Knowlton, *Facts and Principles concerning Steel and Heat Treatment* (Transactions of the American Society for Steel Treating, Jan. 1926, vol. 9, pp. 111–132). The author gives a description of the composition, properties, and uses of some of the common types of tool steels. The classification of plain carbon tool steel according to grade and carbon content is explained. A number of alloy steels are also described.

H. B. Knowlton, *Facts and Principles concerning Steel and Heat Treatment* (Transactions of the American Society for Steel Treating, Apr. 1926, vol. 9, pp. 615–636). The author describes in simple language the mechanism of steel failures. The composition of matter, and the structure and properties of crystals appearing in iron and steel, are discussed. The stresses which cause failure and the internal effects they produce in the metal under stress are explained.

Classified List of Tool Steel Brands (Iron Age, Jan. 7, 1926, vol. 117, pp. 97–100). A list is given of the brands of tool steel manufactured in the United States, together with manufacturer's name and address and type of steel produced.

R. Hohage, *The Heat Treatment of Steel Tools in Collieries* (Kruppsche Monatshefte, Jan. 1926, vol. 7, pp. 1–10). The operations most frequently requiring to be performed upon tools in use in and about collieries are annealing, forging, and hardening. Workshop practice in carrying out these treatments is described, whereby it is shown that the good quality of a tool steel does not depend alone upon its composition, but on its correct treatment in great measure.

C. M. Haight, *Sharpening and Handling Drill Steels at Franklin* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). The author describes the shop procedure at the Franklin Mine of the New Jersey Zinc Co. for the hardening and sharpening of drill steels.

L. Thibaudier and H. Viteaux, *The Question of Steel for Rails and the Heat Treatment at the Neuves-Maisons Works* (Revue de Métallurgie, Mémoires, Feb. 1926, vol. 23, pp. 65–81). In the past, attempts have been made to improve the quality of rails by varying the chemical composition, but experience has shown that the required result has not been attained, and it is clear that heat treatment is the method that can give to the rails the qualities desired in them. The procedure at the Neuves-Maisons works is described: the head only of the rail is given an intermittent quench in a predetermined quantity of cold water, the quantity of water used being a function of the weight of the rail treated. This treatment is given in a special machine immediately after rolling and sawing; the heat contained in the interior of the metal reheats the quenched parts, giving an effect of tempering. The microstructure, and tests on the various parts of rails treated in this way, are described.

P. Nicolau, *Hardening and Tempering Steels* (Iron Age, Feb. 11, 1926, vol. 117, pp. 404, 458–459). A lengthy abstract in English of a paper which appeared in the Revue de Métallurgie, Mémoires, Aug. 1925, vol. 22, pp. 539–544, describing a study of the hardening and tempering effects on the thermo-electric electromotive force of a number of alloy steels.

L. Guillet, *The Properties of Certain Treated Nickel-Chromium Steels* (Comptes Rendus, Jan. 25, 1926). It has long been known that under certain conditions of heat treatment, steels, and especially nickel-chromium steels, develop great fragility, although other mechanical properties may remain unchanged. A systematic study of this phenomenon has been made, and the results of experiments are given in detail.

J. Obenberger, *Heat Treatment of Carbon Steel Die Blocks* (Forging, Stamping, Heat Treating, Nov. 1925, vol. 11, pp. 406–407). A description of the process for hardening die blocks. Only the face of the block is hardened by partial immersion in the quenching water, and when the red colour is leaving the shank the block is removed from the water and the face polished in order to observe the colour changes as its temperature rises again. When the face shows a scleroscope hardness of 65, the whole block is placed in an oil-quenching bath. The faces of blocks treated in this manner show very little warp, and for many purposes the block is ready for use; the shanks will be warped, but may be easily replaned, as they are not hardened. A method of circulating the cooling water and oil is described.

F. Rose, *Manufacture, Heat Treatment, and Average Life of Die Blocks* (Drop Forger, May 1925, vol. 5, pp. 29–41).

C. H. Shapiro, *Dressing and Tempering Fishtail Bits* (United States Bureau of Mines, Report of Investigations: Canadian Mining Journal, vol. 46, Oct. 30, 1925, pp. 1015–1018; Nov. 6, pp. 1027–1029). The dressing and heat treatment of drilling bits used in the oil-mining industry are discussed.

A. H. Frauenthal and C. S. Morgan, *Heat Treatment of Automotive Parts and Description of Equipment Used* (Transactions of the American Society for Steel Treating, Dec. 1925, vol. 8, pp. 851–860). This paper describes the heat-treating plant of the Automobile Machine Company of Cleveland. The methods of heating, carburising, hardening, tempering, and inspecting are discussed.

W. G. Hildorf, *Improvements in Automotive Steels* (Paper read before the American Gear Manufacturers Association, Oct. 1925: Iron Age, 1925, vol. 116, Nov. 19, pp. 1378–1380; Nov. 26, pp. 1447–1450). The author discusses some of the problems encountered in the production of uniform steel for the automobile industry, and enumerates some of the improvements needed in the quality of the steel. Dirty steel, normal and abnormal steels, effect of heat treatment, warpage of steels, fracture testing of steel, woody fractures, impact values and fractures, and grain-size are discussed.

Reducing Costs in Heat-Treating Automobile Parts (Transactions of the American Society for Steel Treating, Mar. 1926, vol. 9, pp. 470–481). An outline is given of the method of heat-treating automobile parts at the plant of the Reo Motor Car Co., Lansing, Michigan. The equipment in use is also described.

A. E. White, *Heat Treatment Data on Quality Steel Castings* (Paper read before the American Society of Mechanical Engineers, Nov. 30–Dec. 4, 1925). A summary of a study made on the heat-treatment practice for quality steel castings. Laboratory and plant tests on dendritic and dendrite-free steels after an annealing, a normalising, a drawing, and a spheroidising treatment show that normalising and drawing give better results than those obtained by annealing or spheroidising.

J. A. Capp, *Annealing Large Castings to Prevent Distortion* (American Machinist (European Edition), Oct. 10, 1925, vol. 63, pp. 385–387). Turbine castings, with which this article is concerned, are liable to warp owing to two kinds of disturbances, those resulting from the machining operations and those caused by temperature variations incidental to the working of the machine when in use. In dealing with these castings, which, while having a large volume space, have only relatively thin walls, webs, and partitions, the General Electric Company in America have found that two short annealings give better results than one long treatment. The castings are examined for visible faults and are then annealed at about 850° C. for four to eight hours, being finally cooled in the furnace. Even after this treatment castings may warp as much as 0·015 inch. Rough machining and patching of small imperfections is next performed, and the annealing process repeated. Iron castings

are annealed at 500° to 550° C. for four to ten hours, and are supported to prevent sagging. An electric car-bottom furnace is used, as the heating is more even than with oil firing.

H. Fulwider, *Electric Annealing of Steel* (Report to the National Electric Light Association at the San Francisco Meeting, June 15–19; Iron and Steel of Canada, Oct. 1925, vol. 8, pp. 208–209).

H. Fulwider, *Annealing Iron and Steel Electrically* (Forging, Stamping, Heat Treating, Nov. 1925, vol. 11, pp. 391–393).

Air-Blast Quenching for Patented Wire (Iron and Coal Trades Review, Jan. 15, 1926, vol. 112, p. 97). Brief particulars are given of the application of an air-blast quenching apparatus to patenting furnaces. It comprises a motor-driven fan with duct, which is furnished with a regulator, and a quench chamber which is fixed to the delivery end of the furnace. The air-blast can be regulated to give an ideal rate of cooling for each gauge of wire from the finest to the heaviest.

E. J. Janitzky, *Observation on Temperature Distribution in Steel Bodies Cooled in Air* (Transactions of the American Society for Steel Treating, Mar. 1926, vol. 9, pp. 452–457). The author describes a method of approximating temperature drops in steel bodies cooled in air to atmospheric temperature.

L. H. Marshall, *A Process for the Prevention of Embrittlement in Malleable Cast Iron* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). Particulars are given of a method of heat-treating malleable castings to prevent brittleness due to hot-dip galvanising. By heating to about 650° C. and quickly cooling, preferably quenching in water, any tendency of the casting to embrittle in galvanising is eliminated.

E. Bremer, *Avoids Embrittlement in Malleable Iron Castings* (Iron Trade Review, Apr. 15, 1926, vol. 78, pp. 992–994, 998). A description is given of a process of heat treatment whereby the brittleness of malleable castings subjected to hot galvanising is prevented.

Boiler Construction.—P. Fischer and K. Schleip, *High-Pressure Boilers* (Kruppsche Monatshefte, Oct. 1925, vol. 6, pp. 185–202). A general account is given of up-to-date practice in the design and manufacture of high-pressure boilers. For working pressures up to 110 atmospheres, seamless nickel steel cylinders of 3 feet diameter with walls $2\frac{7}{8}$ inches thick are used, the material being a 5 per cent. nickel alloy. A table shows the comparative tensile strengths of open-hearth steel plates and nickel steel plates at temperatures ranging from 20° to 500° C.

Springs.—F. H. Brown, *Manufacture of Commercial Steel Helical Springs* (Mechanical Engineering, mid-Nov. 1925, vol. 47, pp. 1053–1055). A brief description of the making of helical springs from spring wire. The varieties of "piano wire" and other materials available for use are described, and the lack of exact definition of these materials is noted.

Welding.—P. Alexander, *Arc Welding in Hydrogen and other Gases* (General Electric Review, Mar. 1926; Chemical and Metallurgical Engineering, Apr. 1926, vol. 33, pp. 216–217). Improved ductility in the deposited metal of an arc weld is obtained by the use of a special tool which directs a jet of the gas used alongside the welding electrode, so that the arc is drawn inside a flame of burning gas. Hydrogen gave very satisfactory results. Other gases were tried, such as water-gas and mixtures of hydrogen and carbon monoxide and hydrogen and nitrogen, and these also came up to expectation. Methanol (synthetic methyl alcohol) is a liquid at ordinary temperatures, but decomposes readily into H_2 and CO at 700° C., and so gives a convenient supply of the former mixture; and ammonia, decomposing into H_2 and N_2 in the presence of a catalyst at 600° C., yields the second mixture. The ammonia is more easily and more cheaply stored than the hydrogen gas, owing to its being liquefiable. The use of these mixtures removes the difficulty of the storage of large quantities of hydrogen gas.

W. L. Warner, *Automatic Arc Welding in Tank Construction* (American Machinist (European Edition), 1925, vol. 63; Nov. 28, pp. 643–645; Dec. 5, pp. 689–692). The development of arc welding to replace riveting is reviewed. The methods of welding and the design of the tanks are described, and strength formulæ are given. Comparisons between hand and automatic welding show the superiority of the latter. Safety factors are considered, and many of the recommendations of the pressure vessel committee of the American Bureau of Welding are given.

J. T. Carr, *Arc Welding Seams in Steel Plates* (Paper read before the Institution of Welding Engineers at Leeds, Jan. 29, 1926; American Machinist (European Edition), Feb. 6, 1926, vol. 63, pp. 282E–283E). The author describes the types of joint most suitable for various thicknesses of plate; he discusses the advantages and disadvantages of each type according to the circumstances. He also indicates the best methods for carrying out the making of the welds and of building up tanks and other appliances by welding.

S. W. Miller, *Welding on Boilers* (Mechanical Engineering, Dec. 1925, vol. 47, p. 1148). A few points, legal and technical, to be remembered when considering the repair of boilers by welding.

A. M. Candy, *Arc Welding Practice and Inspection* (American Machinist (European Edition), Feb. 20, 1926, vol. 64, pp. 43–45). The author points out the necessity for standardised methods in arc welding, and training of the operators. A description of tests on arc-deposited metal is given, and inspection methods are suggested.

A. M. Candy, *Economical Repairs by Welding* (Iron Age, Nov. 12, 1925, vol. 116, pp. 1307–1309). The application of the arc welding process to the repair and maintenance of rolling-mill parts is described and illustrated.

A. G. Bissell, *Adaptability of Electric Arc Welding* (Forging, Stamping, Heat Treating, Nov. 1925, vol. 11, pp. 409–410). Two similar

steel buildings were built, one with structural steel electrically welded and the other by the usual method of riveting. Whereas the riveted building cost 1339·50 dollars, the welded building only cost 786·20 dollars; the field erection cost was slightly greater by the welding process, but the great saving occurred in the cost of preparing the material, and in the shop fabrication. The welding method also used 5½ per cent. less material. Tests for tensile, shear, static, shock, and fatigue strength of welded joints were made and compared with similar riveted joints, and the results were all in favour of the welded joints. In many cases the welds proved stronger than other parts of the beams.

R. A. Storm, *Structural Welding Saves Labour* (Paper read before the American Institute of Steel Construction, Nov. 1925; Iron Trade Review, Nov. 19, 1925, vol. 77, pp. 1270–1271). Describes the construction of a building, 100 feet by 150 feet, with two storeys and a basement. All shop and field connections were electrically welded, no rivets being used at all.

R. Trautschold, *Arc Welding in the Forging Industry* (Forging, Stamping, Heat Treating, Dec. 1925, vol. 11, pp. 430–431). A review of the equipment required for arc welding and of the uses to which it may be put in the forge shop.

F. T. Sisco and H. W. Boulton, *Welding Steel Tubing and Sheet with Chromium-Molybdenum Welding Wire* (Transactions of the American Society for Steel Treating, Nov. 1925, vol. 8, pp. 589–619). In welding chromium-molybdenum steel seamless tubes and chromium-vanadium steel sheet, chromium-molybdenum welding wire produces a weld which has a more uniform structure than low carbon welding wire. In welding chromium-molybdenum steel tubing to plain carbon steel tubing, chromium-molybdenum steel welding wire is not greatly superior and may even be inferior to low carbon welding wire. Welded chromium-molybdenum steel tubing has a soft area about ¾ of an inch from the weld, due to localised annealing, at which spot failure in tension will occur unless the structure is made uniform by heat treatment. Heat treatment consisting of quenching in water followed by tempering greatly improves the structure of welded chromium-molybdenum steel tubing and chromium-vanadium steel sheet at and near the weld. With tempering temperatures of 1000° F. (538° C.) and above, the ultimate strength and elongation are much superior to the untreated tubes and sheets. The effect of heat treatment is not so important in its improvement of physical properties as in the refinement and equalisation of the structure at the weld, although quenching followed by a high tempering temperature improves the ultimate strength and elongation sufficiently to make it advisable to heat-treat all welded chromium-molybdenum steel tubes and chromium-vanadium steel sheets if possible.

J. B. Johnson, *Welding of Carbon and Alloy Steel Tubing for Aircraft* (Paper read before the International Acetylene Association, Chicago,

Nov. 1925). Failures in welded joints can generally be traced to improper welding. The most common cause of failure is the improper fusion of one of the welded parts.

H. Neese, *Electric Welding; Arc Welding of Cast Iron* (Zeitschrift des Vereines Deutscher Ingenieure, Nov. 7, 1925, vol. 69, pp. 1409–1410). The mode of welding cast iron does not differ greatly from that followed in welding steel, but great care is necessary for the avoidance of setting up stresses in the metal. Electrodes of grey cast iron are perfectly satisfactory. Better results are obtained if the pieces are heated before welding.

P. L. Roberts, *The Metallic Arc Welding of Cast Iron* (Electrical Review, Jan. 15, 1926, vol. 98, pp. 93–95). The author describes the welding of cast iron by means of the electric arc. The electrodes may be of cast iron or mild steel; the former can be used in cases where preheating, either local or entire, can be carried out to prevent the setting up of stresses during the cooling of the weld, and the latter are used where the preheating is not possible. Very complete details of the procedure are given, and the difficulties that may, and do, arise are pointed out.

A. R. Lytle, *Effect of Heat of Bronze Welding on Cast-Iron Pipe* (Paper read before the International Acetylene Association, Chicago, Nov. 1925). The most notable advantages in bronze welding of cast-iron pipe as compared with welding with the cast-iron welding rod are said to be the shorter time required for the weld, and the lower temperature at which welding proceeds. The lower temperature permits of successful welding of unpreheated sections, as the contractions of the weld are slight and the stresses set up by cooling are absorbed by the bronze. Another advantage is that the strength of the bronze is greater than that of the cast iron.

J. W. Meadowcroft, *Comparative Strength of Spot Welds and Rivets* (Paper read before the American Welding Society, Oct. 21–23, 1925). Tests were conducted to determine the comparative tensile strengths of spot welded and riveted joints in sheet steel. The results show no substantial differences.

J. R. Dawson, *High Strength Welds* (Journal of the American Welding Society, Oct. 1925). Deals with the welds made by three types of welding rods: "Norway iron" (carbon 0·05, manganese 0·15, silicon 0·01 per cent.), mild steel rod (carbon 0·25, manganese 0·45, silicon 0·02 per cent.), and "high test rod" (carbon 0·20, manganese 0·80, silicon 0·55 per cent.). The author strongly advocates the use of the last-named rod material, and quotes tests to show the superiority of the welds made with it over those obtained with the other materials. He suggests that the presence of the strongly reducing elements prevents the burning-off of the carbon from the steel during the melting of the rod.

H. M. Carter, *Control of Manufacture and Acceptance Tests of Welding Rods* (Journal of the American Welding Society, Oct. 1925). The

author urges the most careful control of the manufacture of welding rod.

J. N. Reeson, *Electric Welding in the Design and Fabrication of Plant and Structures* (Paper read before the Institution of Civil Engineers, Apr. 13, 1926 : Engineering, Apr. 9, 1926, vol. 121, pp. 473–474).

General Electric Automatic Range-Boiler Welders (American Machinist (European Edition), Nov. 7, 1925, vol. 63, p. 568). A brief description with two photographs of these machines for welding boilers from 11 to 33 inches in diameter and up to 6 feet in length.

Portable Two-Operator Electric Arc Welding Plant (Engineer, Nov. 20, 1925, vol. 140, p. 550). An illustrated description of the plant built by the Premier Electric Welding Co., Ltd., London. The machine is fitted with automatic controls so that, although the welding is carried out with a pressure of 35 volts, at the moment of striking the arc the voltage is about 70. The generator is driven by a 17½ horse-power motor running at 1250 revolutions per minute, and supplies 300 amperes to the two welders.

Prescott Spot and Seam Welding Machines (Engineering, Dec. 4, 1925, vol. 120, pp. 724–726). An illustrated description of machines manufactured by British Insulated and Helsby Cables, Ltd., Lancashire.

C. S. Milne, *A Review of the Present Position of Oxy-Acetylene Welding and Cutting* (Engineering, Dec. 18, 1925, vol. 120, p. 779). A report of a paper read before the British Acetylene and Welding Association in London on Dec. 9, 1925. The author combated the opinion widely held that progress in the development of welding processes was slower in Great Britain than abroad. Among other reasons forming the basis of these fallacious beliefs were the use of pressure generators in America, the preference of the carbide-to-water gas generation system in Germany, the supposed inability to cut cast iron, weld copper fireboxes, repair steam boilers, or satisfactorily weld cast iron. The author showed slides of examples of work to demonstrate that the development of oxy-acetylene welding and cutting is as well advanced here as anywhere.

Oxy-Acetylene Cut does not Injure Ductility of Steel (Engineering News Record, 1925, vol. 94, p. 939). The results of tests carried out by the Union Carbide and Carbon Co., New York, show that flame cutting does not injure the metal, both strength and ductility of flame-cut surfaces being equal to those of milled or hack-sawed surfaces. A slight hardening effect is indicated in the strength figures, but the milling off of ⅛ inch from the flame-cut surface removes the hardened metal. The tests indicate that shearing produces marked reduction in ductility.

L. S. Love, *Stampings Assembled by Welding* (Iron Age, Jan. 14, 1926, vol. 117, pp. 123–127). The author gives an illustrated account of the practice at the plant of the Heintz Manufacturing Co., Philadelphia, for the assembly of automobile sheet metal parts by various

forms of welding. A special seam welding machine is utilised in the manufacture of rear axle housings, and by the extensive use of jigs for holding parts to be welded rapid production is facilitated and correct alignment is assured. For certain classes of work a press operation proves more economical than welding.

B. Schapira, *A New Process for Replacing Boiler Tubes* (Chaleur et Industrie, Oct. 1925, vol. 6, pp. 463–465). The tubes are cut, removed from the boiler, and thoroughly cleaned. A sleeve is then welded on, in order to make them tight in the boiler again. The welding process is Priborsky's improvement of Pickal's method; the bevelled edges of the sleeve and the tube are pressed together by two rollers, one within and the other outside. The axes of the tubes are set at an angle to each other, and this gives the tube an axial as well as a rotary motion, so increasing the strength of the weld. The tubes are heated in a continuous furnace, and are finished to the correct size to fit the boiler plates. The preparation of the firebox plates and of their repair by screwed ferrules is also described.

A. M. Lount, *Butt-Welding Multi-Throw Cranks* (Machinery, Nov. 19, 1925, vol. 27, pp. 249–250). The multi-throw cranks referred to in this article are used for certain classes of agricultural machinery. They are formed of six sections, which are welded together after the pins have been turned. The complete sequence of operations, from cutting the stock to the final straightening and testing, is described.

A. V. Harris, *Stellite Surfacing or "Stelliting"* (Paper read before the American Welding Society, Feb. 19, 1926; American Machinist (European Edition), Apr. 3, 1926, vol. 64, p. 311). The process consists in the application of stellite to parts which are required to withstand heat, abrasion or corrosion. It is carried out by oxy-acetylene or electric welding, the former giving the better results.

Pickling.—H. Bablik, *The Pickling of Iron with Hydrochloric and Sulphuric Acid* (Stahl und Eisen, Feb. 19, 1926, vol. 46, pp. 218–222). The nature of the pickling process is discussed. Pickling for the removal of scale proceeds in two reactions, namely, the purely chemical dissolution of the iron oxide by the acid, and the splitting off of the scale due to formation of hydrogen on the iron surface below. In pickling with hydrochloric acid, the first action predominates over the second, but the sulphuric acid is more effective in producing the second action. Superposed on these chemical reactions is an electrochemical one. The dissolving of the iron oxide is facilitated by being first reduced. The speed of pickling increases with the temperature of the bath and the degree of the acid concentration (in the case of the hydrochloric acid up to the point of evaporation); with sulphuric acid the optimum value is at 25 per cent. H_2SO_3, beyond which the speed of the action drops. With a cold bath of sulphuric acid the speed is very low. The effect of adding O. Vogel's pickling reagent to the bath is to accelerate the process, due to the capillary action which that reagent induces.

Tinning.—W. Krämer, *Tinning Machines for Strip Iron* (Stahl und Eisen, Dec. 10, 1925, vol. 45, pp. 2049–2052). The extent of the food-canning industries of the world has shown itself in the huge demands for tinplate. In the last five or six years this latter has been faced with a competitor in the form of tinned strip iron, which is possessed of certain advantages. The older type of tinning machine is illustrated, as are also various improved forms which have been evolved. The provision of more rolls and the separation of the grease bath from the tin bath to allow of better temperature control over the two baths are the principal points of improvement. Lately the use of electricity has been applied to the heating of the baths by submerging heating elements in the contents of the baths. Electricity offers the great advantage of accurate control of the temperatures. The strip, after annealing, is given the usual cleansing treatment and is then wound on drums under clean water; it is wound off these and passed straight through the tinning operation and rewound on a second set of drums. When the first set of strips have been fed through the machine the following ones are fastened to their ends, by folding, grooving, or spot welding. Degreasing plant can, of course, be added after the tinning machine if the strip is to be used for printed or lacquered tins.

R. A. Fiske, *Economises Fuel in Tinning* (Iron Age, Dec. 17, 1925, vol. 116, pp. 1665–1668). The installation of gas-producers at the plant of the Standard Tin Plate Co. at Canonsburg, Pennsylvania, has reduced the fuel consumption for tinning to 3·52 lbs. of coal per base box of tinplate. An illustrated description of the gas-producer plant is given. Two Wellman mechanical producers are used for heating the automatic tinning machines.

PHYSICAL AND CHEMICAL PROPERTIES.

Properties and Tests of Cast Iron.—*Graphite in Cast Iron* (Metal Industry, 1925, vol. 27, Oct. 30, pp. 411–414; Nov. 27, pp. 511–513; 1926, vol. 28, Jan. 1, pp. 15–18; Jan. 8, pp. 39–40). A former series of articles (see Journal of the Iron and Steel Institute, 1925, No. II. p. 469) dealt with pearlite in cast iron. The study of cast-iron metallography is now continued as regards the general nature and influence of graphite in the structure, the solubility of carbon in iron, the effects of other constituents, and "mass" and the effects of varying rates of cooling. The unusual problem of the forging of cast iron is discussed, and the manufacture of a forged cast-iron fuse is described.

H. Jungbluth and H. Gummert, *Influence of Casting Temperature and Annealing on the Size and Development of Phosphide Eutectic* (Kruppsche Monatshefte, Mar. 1926, vol. 7, pp. 41–46). The results of the investigation show that the amount of phosphide eutectic in hot cast pieces is less than in cooler cast ones, but the grain-size and formation are the same. The phosphide eutectic becomes balled together on annealing grey cast iron above 700°. Above that point the phosphorus diffuses extensively into the ferrite, thus reducing the proportion of phosphide eutectic in the iron.

E. Piwowarsky, *The Thermal Treatment of Molten Grey Iron and its Application to Malleable Castings* (Stahl und Eisen, Dec. 3, 1925, vol. 45, pp. 2001–2004). It has already been shown that the more highly carburised iron-carbon alloys, under precisely similar conditions of melting, casting, and cooling, tend to freeze with the carbon in the carbide state after being subjected to superheating at a temperature ranging from 1420° to 1525° C. dependent on the silicon content. If this temperature range be exceeded or not reached the tendency is towards the formation of graphite. With pure low silicon Swedish pig iron variations up to 1·5 per cent. graphite could be produced by varying the overheating of the melt, and on adding 2·5 per cent. silicon to the same iron the graphite could be brought down to 0·2 to 0·3 per cent. The influence of this treatment on the melt was confirmed by an examination of the malleable castings produced from the material. Superheating the melt at 1400° to 1500° delays the dissociation of the carbide on the subsequent annealing of the casting; but moderate overheating or heating beyond 1500° has the opposite effect.

O. Wedemeyer, *Influence of Prolonged Heating on the Crystallising out*

of Combined Carbon in Cast Iron (Stahl und Eisen, Apr. 29, 1926, vol. 46, pp. 557–560). The author has carried out experiments in a coal-fired reverberatory furnace which confirm the observations of Piwowarsky, that the separating out of combined carbon from cast iron depends on the degree to which the pieces were previously heated and on the length of the heating period.

R. Stotz and F. Henfling, *The Contraction and Expansion on Heating of Malleable Cast Iron* (Stahl und Eisen, Dec. 31, 1925, vol. 45, pp. 2137–2147). For practical purposes the contraction of malleable iron may be taken as 2 per cent., provided it is not mechanically restricted. Factors which may cause an alteration in this figure, such as variation in chemical composition, fluidity of the metal, higher pressure, higher casting temperature, the presence of cores, flanges, &c., are considered, and their effects described. The alteration in length on annealing is affected in several ways. An increase in silicon content causes a marked precipitation of temper carbon, with a consequent increase in length. Manganese inhibits the formation of temper carbon, and thereby decreases the expansion on annealing; sulphur has a similar but more marked effect. The higher the carbon content, the greater the amount of temper carbon precipitated, and therefore the greater the elongation. In the white-heart process, thin pieces shrink on account of their decarburisation; in medium-sized pieces the decarburisation and temper carbon precipitation are more nearly balanced, and the contraction and expansion neutralise one another. With still thicker sections the expansion on annealing increases to such an extent that it equals the original contraction of the casting. When annealing black-fracture castings the expansion is independent of the cross-section, but is influenced by the amount of the original carbon content, and by the degree of decarburisation.

E. Richards, *The Resistance of Grey Cast Iron to the Effect of Heating* (Giesserei Zeitung, Dec. 1, 1925, vol. 22, pp. 726–728). The causes leading to permanent growth of cast iron when heated and cooled are discussed.

R. Stumper, *Firebars and their Behaviour in the Furnace* (Chaleur et Industrie, Dec. 1925, vol. 6, pp. 549–554). The destruction of grey cast-iron firebars is brought about by the presence of the graphitic carbon. Air creeps into the interior of the metal by way of the graphite flakes and so accelerates the complete oxidation of the bar. The graphite itself is resistant to oxidation, and may be seen in micrographs to be still present when the rest of the material is completely oxidised. White cast iron resists the oxidising influence of the air better; graphitic carbon precipitates during service, but the material is more dense and the air cannot penetrate in the same way. The sulphur in the fuel has a very marked influence. A new firebar before use and two old firebars after use were examined, and a sample was also taken from near the top of one of the used bars. The results of the analyses show the behaviour of the various elements; the high sulphur in the

top of the old firebar, where it was in contact with the fuel, will be noted :

	New Bar.	Old Bar I.	Old Bar II.	Top of Old Bar.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Total carbon . . .	3·71	3·43	3·57	0·65
Graphitic carbon . .	2·62	0·09	0·13	0·30
Combined carbon . .	1·09	3·34	3·43	...
Silicon	2·196	2·476	2·570	2·804
Manganese . . .	0·54	0·49	0·53	0·49
Phosphorus . . .	0·791	1·11	1·84	1·225
Sulphur	0·152	0·152	0·144	5·90

Hard Spots in Metals (Machinery, Jan. 28, 1926, vol. 27, pp. 569–572). The presence of hard spots in cast iron is largely dependent on the amount and distribution of the combined and graphitic carbon, which are, in turn, influenced by the rate of cooling. The " doctoring " of the metal may be another cause of hard spots, if care is not taken that the addition is completely melted before casting.

Brinell Hardness and Tensile Strength of Cast Iron (Bulletin of the British Cast Iron Research Association, Oct. 1925, No. 10, pp. 6–9). The Brinell test is generally considered an unsuitable test for cast iron, the hardness depending on whether the ball meets matrix or hard spot. Broadly, however, the Brinell hardness will be governed by the phosphide eutectic. The tensile strength will, in the main, be governed by the size and distribution of the graphite, and hence an invariable relation can scarcely be expected. No concordant results were obtained, on two samples of iron, by plotting either actual tensile or actual compression against actual Brinell values. As the thickness increases the hardness decreases and tensile and compression decrease, but there is no definite relationship between the two. The formulæ proposed by Portevin and Schuz for calculating the tensile strength of cast iron from the Brinell figure give values 1·5 to 3 times as great as the actual tensile value.

E. J. Lowry, *Machining Uninfluenced by Hardness* (Address before the New England Foundrymen's Association, Mar. 10, 1926 : Iron Age, Mar. 18, 1926, vol. 117, p. 789). According to the author hardness and strength are not reflected in the wear or machinability of a casting ; the latter two qualities are dependent on the structural forms of the carbon in the iron. The forms of carbon existing in the pig iron are not altered by melting in the cupola, regardless of the rate of cooling the casting. The form of carbon in the casting is dependent on the kind of pig iron used.

T. Klingenstein, *Interrelations of the Mechanical Properties and the Relations of these to the Composition of Grey Cast Iron* (Die Giesserei, Feb. 27, 1926, vol. 13, pp. 169–173). The author considers the

connection between the carbon + silicon content of grey iron and the transverse strength, tensile strength, and Brinell hardness, and also the relation of these properties to each other. The results are well set out in diagrams and tables.

J. W. Bolton, *Correlating Grey Iron Tests* (Paper read before the Congress of Belgian and French Foundrymen, Paris, Oct. 25, 1925 : Foundry, 1925, vol. 53, Nov. 15, pp. 912–915 ; Dec. 1, pp. 959–961; Foundry Trade Journal, 1925, vol. 32, Dec. 17, pp. 507–509 ; Dec. 24, pp. 537–538). Some of the more common mechanical tests for cast iron, the related engineering properties and the correlation of these tests to the structure and composition are considered. Increase in graphite causes decrease in strength, and the tenacity of the metal is lowered by inclusion of a greater amount of this component. The idea of a ferrite network within the graphite, first advanced by Howe, seems plausible. Decrease in strength with increase in carbon usually is more marked in the higher carbon ranges.

M. Rudeloff, *Ring Shear-Tests on Cast Iron* (Stahl und Eisen, Jan. 28, 1926, vol. 26, pp. 97–101). Turned specimens of cast iron with a collar 3·5 millimetres thick were placed over a cylindrical hole and pressure was applied until the collar sheared off. The resistance to shear was found to vary according to the outside diameter of the test-piece and width of collar. With a diameter of 25 millimetres and collar width 3·0 millimetres the shearing resistance was 30·3 kilogrammes per square millimetre, and with corresponding dimensions of 40 and 10·5 millimetres it was 36·1 kilogrammes per square millimetre. The torsion test on bars gave almost equal results.

P. Wolff, *Methods of Testing Cast Iron* (Stahl und Eisen, Apr. 29, 1926, vol. 46, pp. 560–564). The relation between tensile strength, resistance to compression, and hardness of cast iron is discussed, and a method is described of carrying out rapid tests giving sufficiently precise results on samples taken from the cupola immediately before tapping.

H. Thyssen, *Contributions to New Methods of Testing Cast Irons* (Revue Universelle des Mines, Mar. 15, 1926, vol. 9, pp. 297–302). A description of modifications made in a Frémont bend-test machine in order to record very small flexions of the test-pieces. As the deflection of the test-pieces rarely exceeded 0·2 millimetre, it was essential that the apparatus should have a precision of a few thousandths of a millimetre and yet be very strong mechanically, very sensitive, and have a minimum inertia. This was attained by means of a system of levers actuating a pen which traced a line on a revolving drum, the latter being driven by the head of the machine, which applied the load, through a system of pulleys and thread. A safety device was included in order that the recording apparatus should receive no shock at the moment of rupture of the test-piece.

J. W. Donaldson, *The Influence of Special Elements on Grey Cast Iron* (Paper read before the Institute of British Foundrymen : Foundry

Trade Journal, Dec. 31, 1925, vol. 32, pp. 553–556). A review of previous work by various investigators on the influence of special elements on cast iron. The elements which exert the most influence on the properties of grey cast iron are chromium, manganese, tungsten, molybdenum. and chromium-nickel. These elements not only improve the properties of the iron in its cast condition, but in all cases, assuming that molybdenum behaves similarly to tungsten, the stability is increased under low temperature conditions. Chromium to the extent of 0·4 per cent. gives better results than slightly larger amounts of tungsten or molybdenum or than 2·5 per cent. of manganese. Nickel, vanadium, copper, and tin produce slightly better properties in cast iron in its cast condition. Nickel and vanadium, however, accelerate graphitisation under heat treatment, and it is possible that a similar result would be produced by copper. Additions of aluminium or titanium produce no beneficial results, but tend rather to promote rapid graphitisation.

A. Campion, *Cast Iron for Diesel Engines* (Paper read before the North-East Coast Institute of Engineers and Shipbuilders, Jan. 22, 1926: Engineering, Mar. 5, 1926, vol. 121, pp. 315–317). According to the author the essential properties of cast iron for oil-engine parts are: (1) High strength, which must be retained at the maximum temperature to be expected; (2) high resistance to wear by the rubbing action of the piston rings; (3) retention of size and form, with immunity from cracking when exposed to high or fluctuating temperatures. With regard to chemical composition the total carbon should be below 2·8 per cent., and the combined carbon between 0·70 and 0·85 per cent. The silicon should be kept as low as possible and should not exceed 1·5 per cent. The manganese content should be between 1·0 and 1·75 per cent. The most satisfactory limits for phosphorus are 0·25 to 0·5 per cent. The well-known "growth" of cast iron, though small, is troublesome; irons which exhibit the phenomenon most markedly are those whose physical properties are most affected. The growth appears to be connected in some way with the stability of the carbide and the size and quality of the graphite flakes; a reduction of the amount of total carbon and silicon reduces the quantity and size of the graphite flakes, and an increase in the manganese stabilises the carbide, and in these ways the growth may be minimised. Annealing of castings is advantageous in that it removes internal stresses. Suitable low-temperature heat treatment of castings for a Diesel engine will avoid marked changes in size during service. Curves are shown indicating the changes in tensile and other properties caused by heat treatment at various temperatures.

J. G. Pearce, *Cast Iron and Modern Engineering Practice* (Paper read before the Institution of Mechanical Engineers: Iron and Coal Trades Review, Dec. 18, 1925, vol. 111, pp. 1006–1007).

S. E. Dawson, *The Application of Special Cast Irons in the Engineering Industry* (Paper read before the Institution of Engineering Inspection, Feb. 12, 1926: Metal Industry, 1926, vol. 28, Mar. 19, pp. 277–279;

Mar. 26, pp. 303–304; Apr. 2, pp. 327–328; Apr. 9, pp. 351–352). The author outlines the constitution of cast iron, and discusses the effect and distribution of the constituents and the testing of cast iron.

J. E. Fletcher, *Some Fundamental Relationships in Cast Iron, Wrought Iron, and Steel Manufacture* (Paper read before the American Foundrymen's Association: Iron and Coal Trades Review, 1925, vol. 111, Oct. 30, pp. 694–695; Nov. 6, pp. 736–737; Nov. 13, p. 777). The effect of remelting pig iron and the structural differences between cast iron, wrought iron, or steel and the original pig iron are discussed. Little attention has been given to the structural homogeneity of pig iron and to the means for producing irons of regular structure at will. In the three types of pneumatic furnaces used in the industry the slags play an important part in controlling, not only the composition of the metal by thermo-chemical reactions between constituents and the slags, but by their physical condition as mobile fluids acting as absorbers of undesirable migratory constituents such as sulphides and gases, and, by virtue of their heat conductivity or resistivity, aiding or resisting heat flow from the fuel or heating gases to the metal in contact. The ruling types of slags in the transitions from the metastable to the stable neutral compositions are shown graphically. Stress is laid on the stable character of completely graphitised cast iron, steel, and malleable cast iron, wrought iron being placed in the category of a slowly cooled cast iron from which the carbon is removed by oxidation mainly during the semi-solidification of the virtually cooling metal, there being no pearlitic range during the transition. This stable condition of approximately ferritic metal calls attention to the fact that, when cast, pig iron or steel containing combined carbon is of unstable structure. The transition constituents in cast iron, malleable cast iron, and steel are relatively unstable in comparison with wrought iron and dead mild steel. To ensure the maximum stability of a steel containing a mixture of constituents, a suitable heat treatment is necessary in order to mix the constituents homogeneously. In grey cast iron of normal composition the constituents are never homogeneously mixed as ordinarily cast, owing to the differential rate of cooling from the outside to the inside of the mass. Hence the attempts now being made to regularise the structure of cast iron by approaching a structure which is completely composed of pearlite and graphite.

B. Rogers, *Practical Points from Recent Researches in Cast Iron* (Foundry Trade Journal, Nov. 19, 1925, vol. 32, pp. 427–429).

J. E. Fletcher and J. G. Pearce, *The Rapid Determination of Structural or Constitutional Analysis* (Bulletin of the British Cast Iron Research Association, 1926, No. 11, pp. 17–20). The authors describe a method of computing the structural composition of cast iron by weight from the chemical analysis.

Properties and Tests of Wrought Iron and Steel.—W. J. Brooke, *Relationship of Metallurgy to Engineering* (Proceedings of the Lincoln-

shire Iron and Steel Institute, 1918–1920, vol. 1, pp. 27–57). A general discussion of the properties and testing of steels.

Multiple-Lever Universal Testing Machine (Engineer, Apr. 16, 1926, vol. 141, pp. 442 and 446). A description, with illustrations, of a new machine built by Messrs. Joshua Buckton & Co., Ltd. The machine is of 30,000 lbs. capacity, but is designed to occupy a minimum of floor-space and head-room.

Universal Horizontal Testing Machine (Engineering, Jan. 15, 1926, vol. 121, pp. 85–86). A description, with photographs, of a new Amsler machine for making mechanical tests. It is designed for making tensile, compression, and transverse bending tests on round and flat bars, wire and hemp ropes, chains, and manufactured structural parts; compression tests on concrete, cement and stone blocks, and on wooden struts can also be carried out. The testing-loads are applied by pumping oil into two cylinders in which work two frictionless rams. The loads are measured by a pendulum dynamometer, an instrument for recording the oil-pressure.

F. G. Tatnall, *Lawsuit Leads to Design of First Testing Machine* (Iron Trade Review, Dec. 10, 1925, vol. 77, pp. 1466–1468, 1470). The evolution of testing machines is described.

F. Körber and H. A. von Storp, *On the Distribution of Force in Impact Testing* (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1925, vol. 7, pp. 81–97). Describes a method for the construction of a curve to show the relation between the time and the height of fall of a pendulum testing machine, and its use in preparing force-deformation curves. The determination of strain-elongation curves, and of force-deflection curves in bending tests, both in dynamic and static tests, are dealt with also.

F. T. Sisco, *Impact Values of a Nickel Steel* (Iron Age, Dec. 3, 1925, vol. 116, pp. 1513–1514). The author has studied the influence of quenching and drawing temperatures on the Izod values of nickel steel. The steel used had the following composition: carbon, 0·24; manganese, 0·61; sulphur, 0·016; phosphorus (maximum), 0·040; and nickel, 3·52 per cent. The silicon was not determined. The test-pieces were quenched at temperatures between 1425° and 1625° F., and were drawn at 800°, 1000°, and 1200° F. The results of the impact tests and Rockwell hardness values are tabulated. For a drawing temperature of 800° and a quenching temperature of 1425° to 1550° the impact value is confined to the range of 47 to 51 foot-pounds. With higher quenching temperatures, up to 1625° the impact resistance is only 41 foot-pounds. For a drawing temperature of 1000° and a quenching temperature of 1425° F. the impact value is 82 foot-pounds. With higher quenching temperatures the impact resistance tends to be lowered, but not appreciably. For a drawing temperature of 1200° the quenching temperature is not of material difference, the impact value for the 1425° quench being 94 foot-pounds, and for the 1625° quench 97 foot-pounds. The Rockwell hardness for a given drawing temperature was constant and did

not vary with the quenching temperature. Increasing the quenching temperature does not affect the impact resistance after drawing, except possibly when the drawing temperature is below 1000° F. For draws of 800° and 1000° increasing the quenching temperature produces no perceptible coarsening of the grain-size. In the case of the 1200° draw there is probably a slight coarsening when the quenching is 1625° F.

P. Heymans, *Interpretation of Notched-Bar Impact Test Results* (Transactions of the American Society for Steel Treating, Apr. 1926, vol. 9, pp. 604–614). The author describes an investigation of notched-bar impact tests, carried out by means of the photo-elastic method of revealing stress distribution. The shape and dimensions of the notches were analysed under uniform static longitudinal pull and below the elastic limit. The nature of the local failure at the point of maximum stress and its propagation will depend upon the general distribution and also upon the elastic properties of the material. If the material is ductile, a localised excessive stress may only result in local yielding, although if the material is not sufficiently ductile it may give rise to a crack.

S. N. Petrenko, *Comparative Slow Bend and Impact Notched-Bar Tests on some Metals* (Transactions of the American Society for Steel Treating, Nov. 1925, vol. 8, pp. 519–564: United States Bureau of Standards, 1925, Technologic Paper No. 289. See abstract in Journal, 1925, No. II., p. 479).

M. Moser, *The Application of the Notched-Bar Impact Test using Two Specimens* (Stahl und Eisen, Nov. 12, 1925, pp. 1879–1881). Previous investigators have shown that the speed of work effect is very strongly influenced, while the work constant is very little influenced by the temperature at which the impact test is performed. The influence of temperature on these two factors is strongly brought out by the use of two test-bars, prepared from the same material, one of which is twice the width of the other. This method of testing enables it to be judged whether a material has been brought to its best condition in regard to notch-toughness, or, if it shows a lower notch-toughness than is reasonably expected, the cause of the deficiency can be promptly detected; and it can be also readily judged whether the material is capable of being given the proper degree of notch-toughness by suitable heat treatment.

F. Sauerwald and H. Wieland, *The Notch-Bar Test according to the Schüle-Moser Method and the Notch-Toughness of Certain Metals* (Zeitschrift für Metallkunde, 1925, vol. 17, Nov., pp. 358–364; Dec., pp. 392–399).

F. B. Foley, C. Y. Clayton, and W. E. Remmers, *Influence of Temperature, Time, and Rate of Cooling on Physical Properties of Carbon Steel* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). The paper presents the results of an investigation of the behaviour of a steel containing 0·75 per cent. of carbon under the influence of various treatments by a proper control of time and temperature factors. The results obtained in the treatment

of steel containing 0·52 per cent. of carbon by quenching and drawing are also given. The results show that higher values for impact resistance are obtained with a steel of 0·52 per cent. carbon if a drawing at 450° to 675° C. is preceded by quenchings in water from temperatures in the neighbourhood of 1000° C., than when the preparatory hardening is done from temperatures nearer to but above the critical points.

Report of Committee E-4 on Metallography (Proceedings of the American Society for Testing Materials, 1925, vol. 25, Part I. pp. 440–485). A series of hardness tests has been carried out in order to obtain information as to the usefulness of the scratch hardness method. A table is given summarising the results obtained by seven independent observers. The wide variation of the results obtained is partly attributed to the lack of experience in the use of the method. It is believed that the results show the need for a standard method of procedure in addition to that of using the same type of instrument. The report also includes a discussion of the methods employed and some of the results obtained in the study of the crystal structure of metals by means of radiography. A short bibliography of literature on the subject is appended.

R. Mailänder, *The Hardness Testing of Hardened Steels* (Stahl und Eisen, Oct. 22, 1925, vol. 45, pp. 1769–1773; Kruppsche Monatshefte, Oct. 1925, vol. 6, pp. 204–208). Experiments were carried out by the ordinary Brinell method of testing, but the balls used were of varying degrees of hardness, and it was demonstrated that the results obtained were low if the ball used was not considerably harder than the specimen under examination. Using 5-millimetre diameter balls loaded with 750 kilogrammes, or 10-millimetre diameter balls and 3000 kilogrammes load, the limit up to which the hardness figure is sufficiently accurate is about 420 to 450 with ordinary hard steel balls, but with specially hardened cold-worked steel balls it may rise to 460 to 500. Tests showed that even for materials whose hardness lay beyond the above limits, the equation $P = a.d^n$ (P = load, d = diameter of the impression, a and n = constants depending on the material) held true despite the permanent deformation of the ball, but the value of n was also dependent on the hardness and diameter of the ball, and could no longer therefore be regarded as a constant for the material under test.

H. E. Degler, *A Comparison of Methods for Testing Hardness* (American Machinist (European Edition), Oct. 10, 1925, vol. 63, pp. 381–384). A comparison is made of several of the well-known methods of testing hardness, and it is shown that there is some sort of relation between the various hardness values obtained by them. The relation of hardness to strength is considered, and as they are in general dependent qualities, hardness can often be used as a "control" test for the strength of manufactured goods from which test-pieces cannot be taken. The tests are nevertheless only empirical, and if a material is to withstand abrasion it should undergo an abrasive test; if it is to withstand pene-

tration, then an indentation test is required. If, on the other hand, knowledge of the tensile strength or chemical composition is needed, these should be determined direct.

R. H. Greaves and J. A. Jones, *The Ratio of the Tensile Strength of Steel to the Brinell Hardness Number* (Paper read before the Iron and Steel Institute, June 1926: this Journal, p. 335).

C. W. Holmes, *Factors Affecting the Hardness of Steel* (Forging, Stamping, Heat Treating, Sept. 1925, vol. 11, pp. 333–336). The hardness of carbon spring steel is influenced by the temperature to which the steel is heated and by the length of time that it is held at that temperature. Experimental details are described, and results and micrographs are given; the material used had the following composition: carbon, 0·94; manganese, 0·42; phosphorus, 0·019; sulphur, 0·040; and silicon, 0·110 per cent.

S. N. Petrenko, *Elastic Ring for Verification of Brinell Hardness Testing Machines* (Transactions of the American Society for Steel Treating, Mar. 1926, vol. 9, pp. 420–429). The author describes an apparatus which has been designed to provide means for an easy and accurate method of measuring the load in Brinell testing machines. The method consists of measuring deflection of a hardened steel ring in the machine to be verified and comparing this deflection with that obtained in a machine with accurately known loads. The deflection is measured with a micrometer screw permanently attached to the ring. An accuracy of $\pm \frac{1}{6}$ of 1 per cent. at the maximum load of 3000 kilogrammes can be easily obtained with this ring, which is sensitive to a change of about 2·5 kilogrammes. The general methods of verifying Brinell machines are discussed briefly, and the recommendations of the Bureau of Standards for carrying out Brinell tests are appended.

Accuracy in Hardness Testing (Automobile Engineer, Mar. 1926, vol. 16, p. 105). A description of a new hardness testing machine designed by Messrs. Vickers, Ltd. A diamond indenter in the shape of a square pyramid with an angle of 136° is used, as this angle was found to correspond with that included between the tangents to a ball at the edge of an impression when the diameter of the latter was equal to three-eighths of the diameter of the ball. The load is applied automatically, thereby eliminating variations in the speed of application; the load attains its full value in twenty seconds, and is then held for ten seconds. A microscope is attached to the machine and is fitted with special means for measuring the indentation, the dimension of which is read across the diagonal. The control of all the "variables" has been made as complete as possible. (See also *Some Notes on the Use of a Diamond Pyramid for Hardness Testing*, by R. L. Smith and G. E. Sandland, Journal of the Iron and Steel Institute, 1925, No. I. pp. 295–304).

The Firth Hardometer (Machinery, Apr. 8, 1926, vol. 28, pp. 51–52). A small, portable machine, simple to operate and robust in construction, is described. The load is applied through a specially calibrated spring

so as to avoid overloading, and the effect of inertia is also eliminated. A microscope for measuring the indent made by the steel ball forms part of the equipment.

V. Prever and E. Balma, *Safe Loads and the Endurance of Steels under Repeated Bending Stresses* (Ingegneria; Engineer, Jan. 29, 1926, vol. 141, p. 130). The authors point out that most tables giving the safe loads that may be applied to materials under various kinds of stress are based almost entirely on data derived from tensile tests, made under various conditions. They show that many of the definitions of the term "elastic limit" are conflicting, and their opinion is that they are all of more or less doubtful value and validity. Alternating bending stress tests were made on a series of forty-two steels of widely varying composition, using both notched and un-notched bars. The general conclusion reached is that the safe loads and relative coefficients now in use have no mathematical certainty and are purely conventional. The tendency prevalent in practice to assume that the safe load is lower when the velocity of the part to which it is applied is higher—that is, when the total number of reversals of stress is greater—is justified by the authors' experiments, which proved that the practical limits of fatigue are lower in proportion as the number of minimum loadings increases. The authors think that it is irrational to carry out repeated stress tests at a much higher intensity than the part will be called upon to support in practice; their curves show that resistance to high stresses is no proof of the steel's behaviour at medium or low stresses. They consider that it remains to be proved that steels possess any definite fatigue limit. In general, the authors' work demonstrates that medium stresses repeated very frequently for a long time may be just as dangerous as higher stresses for a shorter time or of less frequency, and that the behaviour of materials may often be ascertained with greater accuracy when alternating bending tests are employed instead of alternating tension tests. Photographs of fractures are included in the original paper, showing how the effect of the predominating stress betrays itself by characteristic markings.

F. W. Rowe, *Fatigue Failures in Steel* (Metal Industry, 1926, vol. 28, Feb. 5, pp. 133–135; Feb. 12, pp. 157–159; Feb. 19, pp. 185–186). Many cases of failure, while undoubtedly due to fatigue, may be shown to have been originally caused by surface scratches or sharp changes of section in the member concerned. These defects cause very marked local magnification of the stresses set up in service, which the material is unable to withstand. Again, a steel may have good static mechanical properties but only a low endurance limit, and calculations based on the former will err on the wrong side, and the material may be incapable of sustaining the stresses to be imposed upon it. Some interesting examples of fatigue failures in service are described.

H. F. Moore and T. M. Jasper, *An Investigation of the Fatigue of Metals* (Illinois University, Engineering Experiment Station, 1925, Bulletin No. 152). This Bulletin is a summary of the work of the

investigation of the fatigue of metals carried out since the completion of the work recorded in Bulletin No. 142. The present Bulletin deals with the following subjects: (1) Fatigue strength and static strength of steel at elevated temperatures, (2) the effect on fatigue strength of stress-intensification at a small hole, (3) magnetic analysis as a test for fatigue strength of steel, (4) fatigue strength of non-ferrous metals, (5) fatigue strength of case-carburised steel, (6) testing machines for repeated stress, and (7) miscellaneous test results for metals.

H. F. Moore, *What Happens when Metal Fails by Fatigue* (Transactions of the American Society for Steel Treating, Apr. 1926, vol. 9, pp. 539–552). The author expresses in clear language the action which goes on in a piece of metal when subjected to repeated stress.

P. Ludwik, *Elastic Limit, Cold and Hot Brittleness* (Zeitschrift des Vereines Deutscher Ingenieure, Mar. 20, 1926, vol. 70, pp. 379–386). An investigation is reported on the remarkable behaviour of steel at the limit of elasticity, under the ordinary tensile test, after ageing, and at blue heat, with the object of showing the extent to which the brittleness is dependent upon speed of application of the load, temperature, and condition of stress, and of discovering whether the anomalies can be attributed to any change in the resistance to slip and to pulling apart. Some interesting conclusions are reached.

H. J. French and W. A. Tucker, *Flow in a Low-Carbon Steel at Various Temperatures* (United States Bureau of Standards, 1925, Technologic Paper No. 296). This report deals with flow (elongation) in 0·25 per cent. carbon steel subjected to a fixed load in tension at approximately constant temperature with the range 20° to 595° C. The total flow producing fracture takes place in three distinct steps, the importance of which varies with the applied load and temperature. The three stages of flow are: (1) an initial flow; (2) a secondary flow, at fairly constant rate, which is also considerably less than the rate during the first and third periods; and (3) a final rapid flow just before fracture. As the constant applied load is increased, the initial flow and the rate of flow in the second period increase and the life of the steel decreases. The final rapid flow begins when the reduction in cross-section accompanying appreciable elongation has raised the unit stress to a definite load at each temperature. The relation between decrease in applied load and increase in life is approximately hyperbolic. At atmospheric temperatures there is only a small difference between the loads permitting very long life and those producing fracture in a few moments. As the temperature is raised the increase in life with decrease in applied load becomes more gradual. An important effect of temperature increase is to reduce the strain-hardening ability of the steel. This is a maximum at ordinary temperatures and decreases until it becomes zero in the neighbourhood of 400° to 425° C. As a result the principal factor governing the maximum allowable stress varies with temperature and type of service.

P. Chevenard and A. Portevin, *Elastic Properties of Alloys: Varia-*

tion as a Function of the Chemical Composition (Paper read before l'Académie des Sciences, Nov. 23, 1925: Comptes Rendus, vol. 181, p. 780).

E. G. Coker, *Photo-Elastic Methods of Measuring Stress* (Minutes of Proceedings of the Institution of Aeronautical Engineers, No. 17).

W. E. Dalby, *The Mechanical Properties of Steel* (Paper read before the Institution of Civil Engineers, Nov. 17, 1925: Engineering, Nov. 13, 1925, vol. 120, p. 625). The author's researches on the mechanical properties of steel, and the results obtained by photographic recorders, are described. Diagrams show that a push-pull cycle or a torque-twist cycle on a metal gives a characteristic curve which maintains its general shape as the cycle is repeated, though with slightly changing boundaries. This curve is called the plastic contour of the metal. The author concludes that metal fails by slipping in whatever manner the external load may be applied, and that the metal retains elastic quality during and after the slipping; when the load is removed, even after slipping almost to fracture, the metal shrinks elastically. This, however, gives no explanation of the fact that, after failure by slipping in either push-pull or torque-twist processes, a reduction of load is met by an elastic response. The plastic contour shows, however, that with a reversal of the load this elasticity almost disappears and plastic yield occurs. The author suggests that the examination of the plastic contour may explain many failures which have hitherto been considered mysterious.

J. Seigle, *Some Theoretical and Experimental Peculiarities in the Torsion of Non-Cylindrical Bars* (Revue de l'Industrie Minérale, Dec. 15, 1925, No. 120, pp. 555–566). Experiments were carried out with soft steel bars of various sections. The author shows how the mathematics of the torsion of bars of non-circular section, stressed beyond the elastic limit, depart from those of a cylindrical bar. He studied the effects of such torsional strains on non-cylindrical bars, such as the alteration in length of the specimen, the partial change of crystal structure, and the behaviour of the latter on annealing.

J. Seigle, *Elastic Limit and Resistance to Rupture of Bars Submitted to Combined Torsion and Tension or Compression* (Génie Civil, Oct. 24, 1925, vol. 87, pp. 345–349).

F. Crestin, *Comparison of the Elastic Limits of Hard Steels under Tension and under Shear by Torsion* (Génie Civil, Jan. 2, 1926, vol. 88, pp. 6–9). The subject is treated mathematically.

W. S. Montgomery, jun., and E. R. Enders, jun., *Some Attempts to Measure the Drawing Properties of Metals* (Mechanical Engineering, Feb. 1926, vol. 48, pp. 119–124). Tests were made to show whether any relationship exists between the ordinary mechanical properties of sheet metals and their ability to draw well. Rockwell, Herbert time, Herbert scale, Herbert work-hardness, Herbert flow, and Erichsen tests were carried out, and by comparison of the indications given by these trials with actual drawing tests it was concluded that the Erichsen

test, in conjunction with micrographs, gave the most reliable indication of the "drawability" of the material.

H. S. Marsh and R. S. Cochran, *Drawability of Sheets and Strips* (Iron Age, Nov. 5, 1925, vol. 116, pp. 1251–1252). In testing sheets by the Erichsen ductility machine the results are expressed in terms of both the gauge and the depth of impression. Since sheets of the same quality but of different gauge are drawn to widely different depths, it is difficult to avoid confusion. The authors have established the relation between these two variables, and have prepared a chart which enables the results to be converted instantly to a single figure. The testing of sheets by this method, which is known as the Marco system, is described.

F. B. Foley and J. E. Crawshaw, *Effect of Air Gap in Explosion System on Production of Neumann Bands* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). In order to demonstrate experimentally that the development of Neumann bands was determined by the suddenness of the deformation of the metal in which they were produced, use was made of explosives as the source of energy, an air gap being interposed between the charge and the disc of steel. The specimen which had no air gap between it and the explosive showed numerous Neumann bands. With an increase in the air-space from 4 up to 16 millimetres there is little change in the appearance under the microscope as shown by the photomicrographs. The number seems to decrease gradually until with an air gap of 128 millimetres no bands appear at the centre of the specimen. So far it has not been found possible to detect Neumann bands in steel that has been subjected to very sudden deformation, unless the steel contains an excess of free ferrite. Thus the microscopic examination of steel for Neumann bands is confined to very low carbon steel in the annealed state. Some tests were made to determine the effect of Neumann bands on the solubility of iron in hydrochloric acid. The results indicate that an accurate determination of the losses in dilute acid will probably show the existence of a relationship between the solubility of the metal and the degree of deformation or twinning that the specimens have undergone under the action of the explosive.

H. Meyer and F. Nehl, *The Underlying Principles on which Plastic Deformation Proceeds* (Stahl und Eisen, Nov. 26, 1925, vol. 45, pp. 1961–1972). A theoretical consideration of the compression test as the starting-point for studying the process of deformation in forging, pressing, drawing, and rolling.

J. Seigle, *The First Permanent Deformations in Soft Steels. The Conditions for their Appearance and Development* (Génie Civil, 1926, vol. 88, Apr. 3, pp. 315–317; Apr. 10, pp. 332–336; Apr. 17, pp. 357–358). The deformation of specimens of soft steels may be investigated by an examination of the Lüders lines or by etching with a suitable reagent. The former method has the advantage of showing the gradual development of the deformation, whereas the latter can be applied to

the interior of the test-piece after it has been sectioned. The various phenomena that may be observed when test-pieces of different shapes are tested in different ways (tensile, compressive, and bending tests) are described.

A. Portevin and P. Chevenard, *The Influence of Cold-Working and Quenching on the Elastic Properties of Various Metals and Alloys* (Paper read before l'Académie des Sciences, Nov. 16, 1925: Comptes Rendus, vol. 181, p. 716).

G. Masing, *Internal Stresses in Cold-Worked Metals* (Stahl und Eisen, Oct. 22, 1925, vol. 45, p. 1787). The author distinguishes between three types of internal stress. During the cold-working of metals the particles are displaced against each other, thereby setting up internal stresses of various "signs." For the demonstration of these stresses a sufficiently low temperature is necessary, as they are liberated partly mechanically and partly by recrystallisation at high temperatures. During the cold-working a second variety of stress occurs; these are explained on the assumption (based on a simple model) that in the worked material components having the same elastic modulus but different elastic limits lie next to each other. If the external load exceeds the lower but not the higher limit, elastic tension and compression stresses are set up on its removal. If the external load is renewed in the same direction, then these internal forces raise the elastic limit, but if in the opposite direction they lower it. A third variety of internal stress accompanies the distortion of the crystal lattice and is the cause of the increase in tenacity. The three types can be distinguished by actual observation, because the first variety disappears comparatively rapidly at quite low temperatures, the second at high temperatures, while the third is removed (and with it the increase of tenacity) when recrystallisation at high temperature has occurred.

D. J. McAdam, jun., *Effect of Cold-Working on Endurance and Other Properties of Metals* (Transactions of the American Society for Steel Treating, Dec. 1925, vol. 8, pp. 782–836). Part 1 of this paper includes a number of graphs illustrating the effect of cold-working on tensile strength, yield point, shearing strength, yield ratio, shear ratio, and Meyer hardness indices. The possible relationship between the effect of cold-working on these properties and the effect on endurance limit is discussed. Part 2 presents a number of graphs illustrating the effect of cold-working on ductility and on some strength values, the calculation of which depends on ductility values. The metals under investigation were all non-ferrous, with the exception of Armco iron.

V. N. Krivobok, *A Photomicrographic Study of the Process of Recrystallisation in Certain Cold-Worked Metals* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). The mechanism of recrystallisation was studied by subjecting electrolytic iron and single crystals of an iron-silicon alloy to cold-working.

The changes in the structure are explained and numerous photomicrographs are given. The development of Neumann bands is discussed. The process of recrystallisation can be briefly summarised as follows: when a metal is subjected to cold-work, the orientation of its grains as a whole is undoubtedly preserved, while distortion is highly concentrated and affects only minute volumes of crystalline material. These portions take the form of narrow streaks, straight in general direction, bounded by lines sometimes smooth, but generally arranged in saw-tooth pattern. When this cold-worked metal is heated, the portions previously distorted and left in a disorganised state tend to revert to their most stable and stress-free condition. Those areas where the bonds of the old structure are most completely loosened will recrystallise first with new orientation, and it is seen that these centres are entirely confined to the material included in the strain markings. These small grains are found to grow at first in such a way as to cause recrystallisation within the "markings," the metallic mass between the markings remaining unaffected and structureless. As the process of recrystallisation continues the grains penetrate the structureless mass, until finally the whole body of the metal is completely recrystallised. Apparently, one of the conditions of recrystallisation is the time that is permitted to elapse between the cold-working and the heating. Repeated observations on samples have always given the same result: complete recrystallisation has been caused by cold-working only if immediately followed by heating. If a certain length of time was permitted to elapse between heating and cold-working the samples have always contained traces of incomplete recrystallisation.

V. N. Krivobok, *Thermal Disturbances and Recrystallisation in Cold-Worked Steels* (Transactions of the American Society for Steel Treating, Dec. 1925, vol. 8, pp. 703–720). The paper gives the results of thermal analysis of cold-worked hypoeutectoid steels. Steels with carbon up to 0·50 per cent. and Armco iron show an evolution of heat below the critical range. This evolution creates on the critical curve a point similar in every respect to the standard critical points, but opposite in sign. It is arbitrarily designated the Ax point. Its position is not always constant and fixed. It seems quite reasonable to assume that the Ax point indicates both recrystallisation and a relief of internal strains. The point is not of the reversible type: it disappears entirely after the first heating of the cold-worked sample; hence its appearance must be closely connected with the specific properties imparted by cold-working. A number of curves are included in the paper, together with the results of microscopic examination.

F. C. Langenberg, *Effect of Cold-Working on the Strength of Hollow Cylinders* (Transactions of the American Society for Steel Treating, Oct. 1925, vol. 8, pp. 447–473). The paper opens with a discussion of the principles involved in the computation of the strength of gun tubes and jackets. The main portion of the paper is devoted to a

description of a process of manufacture in which the physical properties of large hollow cylinders are greatly improved. In the process the bore is stressed beyond the elastic limit by means of hydraulic pressure. After a cylinder has been permanently expanded, the elastic conditions within its walls vary from tangential compression near the bore to tangential tension on the outside of the cylinder. The apparatus employed in the manufacture of gun tubes by the cold-working process is described in detail. The effect of annealing operations on the elastic strength of cold-worked simple and compound cylinders after the application of different amounts of cold-work is also studied.

C. Y. Clayton, *The Effect of Annealing upon the Hardness of Cold-Worked Ingot Iron* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). The author describes some tests which show that iron with a carbon content of 0·03 per cent. hardens upon being annealed at a temperature within the blue-heat range between 250° C. and 425° C. regardless of the amount of cold-compression work that might have been put upon it. Samples compressed under loads of 20,000 to 40,000 lbs. softened upon being annealed between 500° C. and 600° C., but samples compressed under loads of 10,000 and 15,000 lbs. remained hard on annealing.

G. L. Kelley and J. Winlock, *On the Restraint of Exaggerated Grain Growth in Critically Strained Metal* (Journal of the Franklin Institute, Jan. 1926, vol. 201, pp. 71–77). The authors experimented with sheets of aluminium and low-carbon steel. Contradictions and exceptions in the experimental work were frequent enough to interfere with a clear view of the results, but sufficient evidence was obtained to make it possible to state that exaggerated grain growth in critically strained metals may often, though not always, be restrained or even prevented by a preliminary heating for a more or less lengthy time at temperatures below that at which this type of grain growth would normally occur.

Report of Committee E 1 on Methods of Testing (Proceedings of the American Society for Testing Materials, 1925, vol. 25, Part 1, pp. 398–439). Proposed methods of flexure testing of metallic materials, and of torsion testing to determine the mechanical properties of metallic materials under shearing stress, are submitted.

J. Cournot and K. Sasagawa, *The Viscosity of Some Alloys when Hot* (Comptes Rendus, 1925, vol. 181, pp. 661–662). The viscosity limit of a metal at a given temperature is defined as the limiting load below which the metal shows no elongation. Experiments were carried out on various steels. Wire specimens 1 mm. in diameter were tested in an apparatus in which the load was kept constant notwithstanding the reduction in cross-section of the wire. The time elongation curve was registered automatically. At 600° the following increases in load (kg./mm.^{2}) were required to pass from the viscosity limit to a rate of flow of 16×10^{-4} mm. per hour, with wires 100 mm. in length: mild steel, 4·2 to 5·2; semi-mild steel, 4·3 to 5·6; high-speed steel, 14·0 to 19·0; nickel-chromium-iron alloy (63 per cent. nickel, 11 per cent.

chromium), 32·0 to 36·0; and silicon-chromium steel (2 per cent. silicon and 12 per cent. chromium), 30 to 35·5. The viscosity limits of these metals are tabulated.

W. Rosenhain, *The Use of Metals at High Temperatures* (Metallurgist, Jan. 29, 1926, pp. 2–4). A discussion of the manner in which high temperatures affect materials in service, and the mechanism of their resistance under such adverse conditions. When a piece of metal is heated steadily and has to sustain a steady load, the information yielded by the "creep" test is of great importance; these conditions are not, however, met with in practice. It may frequently happen that the metal is only partially heated, or from one side only, as in an internal combustion engine piston; the remaining metal exerts a powerful "backing-up" effect. The important point is the temperature gradient, which is also a "strength gradient," and in the selection of materials to withstand high temperatures their physical properties should be considered not only at the maximum temperature but at all other temperatures below, down to the normal.

O. A. Knight, *Behaviour of Steel at Elevated Temperatures* (Forging, Stamping, Heat Treating, Jan. 1926, vol. 12, pp. 36–40). In the experiments carried out by the author the test-pieces, in the form of wire, were subjected to a predetermined load, which was maintained during the heating and cooling down of the specimen. The material was cold-drawn steel wire, 0·097 inch in diameter, and having the following composition: C, 0·17; Mn, 0·42; Si, 0·03; S, 0·026; and P, 0·015 per cent. With various loads certain temperatures were noted beyond which permanent sets occurred. It was found that to heat the wire while under load had the effect of increasing its resistance to deformation. The blue-heat phenomena and elastic limit recovery by low-temperature annealing after overstrain were said to be due to the same cause, but the experiments show that the effect is much greater when the straining and annealing occur simultaneously than when they occur separately.

V. T. Malcolm, *Metallurgical Developments in the Valve and Fitting Industry* (Mechanical Engineering, Dec. 1925, vol. 47, pp. 1141–1143). The use of high temperatures and pressures in modern power plant has necessitated the development of steel and other alloys with superior properties. A description is given of some of the tests carried out in the laboratory with which the author is associated.

Mahoux, *Internal Combustion Engine Valves* (Iron Age, Feb. 4, 1926, vol. 117, p. 339). An English abstract of a paper appearing in Revue de Métallurgie, Mémoires, Jan. 1925, vol. 22, pp. 39–51, giving the results of an investigation of the behaviour of mushroom valves under conditions required in modern aero and other engines. (See also this Journal, 1925, No. II. p. 489.)

J. B. Johnson, *Relationship of Metallurgy to the Development of Aircraft* (Transactions of the American Society for Steel Treating, Apr. 1926, vol. 9, pp. 517–538). The author describes the development of the

metal structure of aeroplanes in America and the various types in use on the Continent. The paper sets forth the wide variation in the physical properties and chemical analysis of the materials used, and points out that an actual saving in weight has been accomplished by the introduction of the metal fuselage.

J. F. Keller, *Why Metal Warps and Cracks* (Transactions of the American Society for Steel Treating, Mar. 1926, vol. 9, pp. 373–402). The author discusses the various factors which come into play in causing iron and steel bodies to warp or crack when subjected to heat. The subject is dealt with under the following headings: Expansion, transformation points, and loss of strength; the effect of resistance to expansion in length; column-action; the effect of resistance in cooling; reduction in diameter of mass due to resistance; repair welding; cooling of castings; internal ruptures; warpage due to localised heating; shortening of length by repeated heating and cooling of steel; warpage due to unequal cooling; warpage and cracking in tool steel.

W. Kerr, *Failure of Metals by Creep* (Paper read before the Institution of Engineers and Shipbuilders in Scotland, Jan. 12, 1926). The author points out that the primary neglect of the influence of the time factor in high-temperature testing no doubt arose from its apparent unimportance in the normal cold test. A stress which, at a given temperature, would not cause fracture under the ordinary condition of quick loading was still potentially destructive, if allowed time. The process of failure was by a creeping action, or viscous flow of the material, so slow as to be difficult of detection, but continuous until rupture occurred. The material might endure the imposed stress for a long time, but if creep were established, ultimate disruption was assured.

G. L. Gérard, *The Calculation of the Strength of Metal Pieces under Simultaneous Bending and Compression* (Revue Universelle des Mines, Oct. 1, 1925, vol. 8, pp. 6–20).

C. W. Ham and J. W. Huckert, *An Investigation of the Efficiency and Durability of Spur Gears* (Illinois University, Engineering Experiment Station, 1925, Bulletin 149). The report records the results of an investigation carried out to determine the efficiency of spur gearing, and the change and rate of change in the profiles of spur gear teeth subjected to wear. A complete bibliography of the literature on the efficiency, durability, and strength of gear teeth is appended.

E. C. Clapp and F. C. Devereaux, *Tests with Molybdenum Steel Balls at Matahambre, Cuba* (Engineering and Mining Journal, Dec. 5, 1925, vol. 120, p. 891). Comparative tests were made on chrome steel and molybdenum-treated chrome steel balls, used for grinding in ball mills. The consumption of the molybdenum-treated chrome steel balls per ton of ore ground was 0·742 lb., whereas that of the chrome steel balls was 1·110 lb. Against that advantage must be set the fact that the first cost of the molybdenum-treated balls was about 0·6 cent

per lb. more than for chrome steel balls. A few of the molybdenum-treated balls were found to split into hemispheres, but this did not appear to affect their grinding powers, and they did not break up further.

V. L. Eardley-Wilmot, *Molybdenum* (Canada, Department of Mines, Mines Branch, 1925, Report No. 592, pp. 240–258). A summary is given of the published literature on the properties and commercial uses of molybdenum steels and molybdenum alloys.

H. J. French and T. G. Digges, *Experiments with Nickel, Tantalum, Cobalt, and Molybdenum in High-Speed Steels* (Transactions of the American Society for Steel Treating, Dec. 1925, vol. 8, pp. 681–702). The tests described in the paper form part of an investigation of the effects of chemical composition on lathe tool performance of high-speed steels. With the exception of a chromium-tantalum steel the steels used were modifications of the tungsten-vanadium types in commercial use. In some cases, the usual proportions of chromium, tungsten, and vanadium were increased, as in the steels containing nickel and cobalt, while in some of the steels, such as those containing molybdenum or tantalum, the special elements were substituted for all or part of one of the customary constituents. The roughing lathe tool performance of tungsten-vanadium high-speed steels was not materially affected by the addition of 3·7 per cent. nickel, a like amount of cobalt, or the replacement of part of the tungsten by molybdenum. To develop best tool performance higher hardening temperatures were required for the steels containing nickel than those without appreciable amounts of this element. In this respect nickel and cobalt are alike, and the peak of the high heat temperature—" Taylor speed "—curves was found at approximately equal temperatures. Nickel, however, adversely affected the cutting capacity of the high-speed steel to a greater degree than cobalt. Molybdenum as a replacement of a large part or all of the tungsten in high-speed steels is not desirable. Of three steels in which tantalum and columbium were substituted for other elements, only one showed red hardness, and its performance was relatively poor. The other two would not cut, and one of these could not be hardened.

Dempster Smith, *Second Report of the Lathe Tool Research Committee* (Transactions of the Manchester Association of Engineers, Session 1924–1925, pp. 337–384). The report deals with the behaviour of lathe tools when cutting cast-iron.

E. G. Herbert, *The Measurement of Cutting Temperatures* (Paper read before the Institution of Mechanical Engineers, Feb. 19, 1926: Engineer, Jan. 1, 1926, vol. 141, p. 24; Engineering, 1926, vol. 121, Feb. 5, pp. 185–186; Feb. 12, pp. 213–216). The operations involved in cutting metals with hard steel tools all generate heat, which gives rise to two effects that are of importance. It heats the tool itself and may thereby destroy its cutting properties, and it heats the work, which may lose some of its valuable physical properties. The

difficulty of measuring the temperatures was got over by making the tool and the work form a thermocouple; this was not very difficult when the work was a non-ferrous metal, but it was even found possible in some cases to obtain an electromotive force sufficient for temperature measurements when cutting mild steel. By the use of Professor Einthoven's string galvanometer and photographic recording apparatus it was possible to obtain data relating to operations where the heat fluctuations were very rapid, such as in shearing, press work, and, in general, processes employing blows.

J. Strauss, *Cutting Tests of Tool Steels* (Transactions of the American Society for Steel Treating, Apr. 1926, vol. 9, pp. 571–584, 648). The author deals with the cutting ability of tools and tool steels and the cutting resistance of metals. The three classes of tools for cutting metals are enumerated, and a description is given of the various experimental tests made in determining the failure of tools. The general precautions necessary to be taken in the various methods of testing are set forth. A short bibliography of the literature of the subject is appended.

A. H. Kingsbury, *Tungsten Steels* (Transactions of the American Society for Steel Treating, Apr. 1926, vol. 9, pp. 597–603). The author describes briefly the characteristics and application of the different types of tungsten steel used for cutting tools.

M. A. Grossmann and E. C. Bain, *On the Nature of Some Low Tungsten Tool Steels* (Transactions of the American Society for Steel Treating, Feb. 1926, vol. 9, pp. 259–276). The authors have studied the hardness, toughness, shrinkage, and microstructure of low tungsten tool steels containing 3·0 per cent. tungsten and a little over 1·0 per cent. carbon. Both oil- and water-hardening steels were investigated. The oil-hardening steels consist of a mixture of martensite and austenite throughout, while the water-hardening steels have this structure at the surface only. The centre of the water-hardening steels is largely troostitic. In addition to a rather unstable austenite decomposing at 500° F. there is a small amount of stable austenite decomposing only at 1100° F. The hardness curves of the oil-hardening steel show secondary hardness at the low drawing temperatures, as well as a slight hardening at 1100° F. The impact toughness curves show initial toughening upon tempering, then brittleness at about 500° F., and then pronounced toughening. The heat treatment generally recommended for the oil-hardening grade is a quench at 1650° to 1700° F., followed by tempering at about 350° F., which offers the best combination of hardness and toughness.

J. P. Gill and M. A. Frost, *The Chemical Composition of Tool Steels* (Transactions of the American Society for Steel Treating, Jan. 1926, vol. 9, pp. 75–98). The authors discuss in detail the chemical composition of various types of American tool steels.

H. Scott, *Dimensional Changes Accompanying the Phenomena of Tempering and Ageing Tool Steels* (Transactions of the American Society for Steel Treating, Feb. 1926, vol. 9, pp. 277–304). The author has

investigated the means of controlling the length changes that occur in normally hardened tool steels with time at ordinary temperatures. It is shown that contraction and expansion with time is identified with the initial contraction and expansion on tempering. Previous determinations of the volume changes on hardening have shown that all steels increase in specific volume on quenching, provided the amount of austenite retained is not exceptionally high. These observations are confirmed by the results of the experiments described. The volume change is mostly in diameter with surface-hardened steels. With fully hardened steels the volume change is mostly in length when the quenching temperature is low, but when it is high the unit diameter change is greater than the unit length change. In tempering, the unit changes in fully hardened steels are practically the same in length as in diameter; this is not the same for surface-hardened steel, which changes more in length than in diameter. Three stages of volume changes on tempering low alloy content tool steels have been recognised: First, a contraction which reaches a minimum on tempering one hour at between 150° and 200° C.; second, an expansion to a maximum at about 260° C.; and third, a contraction to a minimum at a temperature between 400° and 500° C., at which minimum the density of the steel has returned to that in the annealed condition. The contraction is caused by the decomposition of martensite, and the expansion by the transformation of austenite to martensite. Time changes were measured for ageing at 100° C. and at ordinary temperatures. All steels continuously quenched and untempered contracted with time; the rate of contraction was much greater when aged at 100° C. than at ordinary temperatures. After six months at ordinary temperatures the contraction was about the same as after one hour at 100° C. Specimens cooled in air through the hardening transformation expanded with time, but not definitely faster at 100° C. than at ordinary temperatures.

British Standard Specification for Steel Roller Chains and Chain Wheels (British Engineering Standards Association, Report No. 228, 1925).

British Standard Schedule of Steel for Die Blocks for Drop Forging (British Engineering Standards Association, Report No. 224, 1925).

British Standard Specification for Cast-Iron Filter Plates and Frames (British Standard Specification for Cast-Iron Filter Plates and Frames, Report No. 189, 1925).

A.S.T.M. Standards (Proceedings of the American Society for Testing Materials, 1925, vol. 25, Part 1, pp. 509–917). The tentative standards for various materials submitted or revised during 1925 are given.

National Bureau of Standards (United States Bureau of Standards, 1925, Circular No. 1, second edition). An illustrated account of the functions and activities of the Bureau of Standards.

A. P. Hague, *The Choice of Steel for General Engineering Purposes* (Paper read before the Institution of Mechanical Engineers (Yorkshire

Branch), Feb. 12, 1926). The author discusses the tests best suited for ascertaining the physical properties required for resisting any particular type of stress or stresses, and indicates certain failings of the tensile test when applied to alloy steels. The Wöhler method of determining the elastic range of material and the relationship between the results so obtained and those obtained with the tensile test are also discussed. The close connection between the ultimate stress and the fatigue limit of certain steels is pointed out, and the necessity for the use of the notched-bar test is urged. Typical physical properties of the materials now available are given, acid and basic steels, forged and rolled materials, drop forgings, and certain special steels being commented on and discussed. Examples of failures in service of various kinds are given. By designing structures on the proof stress and fatigue limit, and taking due account of the ductility and notched-bar values, considerable saving in weight and probably ultimate cost may be possible.

The Properties of High Silicon Structural Steel (Stahl und Eisen, Apr. 15, 1926, vol. 46, pp. 493–503). The results are recorded of a series of tensile tests on rolled bars containing about 1 per cent. of silicon and 0·10 per cent. of carbon. The material for the tests was produced in the Bosshardt furnace, the bars being rolled from ingots of 450 kilogrammes weight. The results confirm those of Hadfield and other investigators, namely, that the tensile strength, and particularly the elastic limit, are increased by an addition of silicon up to 1 per cent., without any appreciable lowering of the elongation and contraction. Silicon steel produced by any of the usual processes exhibits the same characteristics.

Recent Developments in Rail Steel (Iron Age, Feb. 4, 1926, vol. 117, pp. 336–338). Two short articles are given, the first of which deals with a new low manganese steel for rails. The steel is of the following composition: Carbon from 0·30 to 0·85, manganese 1·15 to 1·90, phosphorus not to exceed 0·05, and silicon not to exceed 0·30 per cent. With a carbon content of 0·50 to 0·60 per cent. the manganese should be about 1·50 per cent. Where the carbon runs down to the lower range (0·30 per cent.) the manganese may run up to as high as 1·90 per cent. With the proper proportion of carbon and manganese, a steel of high tensile strength and elastic limit with a good elongation and reduction of area is produced, and one which contains little or no crystallisation. It is also claimed that by the use of this steel for rails a smaller section can be employed and the risk of transverse fissures is greatly reduced. In the manufacture the manganese should be added in the furnace and not in the ladle. The second article discusses briefly some of the problems connected with transverse fissures.

C. E. Chase, *Research and Experimental Tests in Connection with the Design of the Bridge over the Delaware River between Philadelphia and Camden* (Journal of the Franklin Institute, Oct. 1925, vol. 200, pp. 417–436). Before preparing the designs of this bridge it was decided to

test out afresh many rules of design that have in general been sanctioned as good practice, as it was felt that in some cases the data on which these rules had been founded were inadequate. This applied in particular to the cable work of the bridge, which is of the suspension type, and much information is given of the tests and experiments that were carried out on the wires, strands, and cables.

F. C. Lea, *The Evolution of Iron and Steel Bridges* (Paper read before the Society of Engineers and Metallurgists, Sheffield, Oct. 20, 1925: abstract, Engineering, Nov. 13, 1925, vol. 120, pp. 603–604). The author describes the evolution of metal bridges from the first cast-iron structure built at Coalbrookdale in 1778, up to the present day. He shows how the development of the art of fabricating materials, of the science of testing materials, the theory of elasticity, and the theoretical principles underlying the design of structures have combined to make possible the advances which have been achieved.

L. P. Sidney, *The Metallurgical Aspect of Modern Boiler Practice* (Chemical Age, 1926, vol. 14, pp. 2–3). The growing necessity of fuel economy is causing changes in boiler pressures and temperatures, and therefore in boiler construction. The strength of boiler plate can be increased by the use of high-quality steel containing nickel and chromium.

E. Siebel and F. Körber, *Tests to Determine the Stress and Deformations of Domed Boiler Bottoms with and without Manhole, due to Internal Pressure* (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, Abh. 59, 1926, vol. 7, No. 10, 177 pp.). An exhaustive report on an investigation to determine the distribution of stress on domed boiler ends by means of measuring surface stretchings and bendings. The most suitable form for boiler ends with and without manholes is suggested.

T. S. Wheelwright, *Electric Steel for Staybolt Use* (Iron Age, Nov. 5, 1925, vol. 116, p. 1243). The author presents the results of tests showing the superiority of electric steel over puddled iron for the manufacture of staybolts for locomotive use. The tests show a higher elastic limit and tensile strength in the steel as well as a greater elongation and reduction of area.

J. H. S. Dickenson, B. Gray, and F. E. Cherry, *The Selection and Properties of Steels for Oil-Well Boring Equipment* (Journal of the Institution of Petroleum Technologists, 1926, vol. 12, pp. 1–31). The authors indicate the most appropriate kinds of steel for oil-well tools and casings and for oil-well equipment generally. A table is given showing the type of failure to which the tools and parts are liable, and a study of the modes in which failure may occur is useful in making a systematic selection of the steels best suited for the particular purpose The best composition of the different kinds of steel is stated, with notes as to the appropriate heat treatment.

N. S. Otey, *Testing Metals for Aircraft* (Iron Age, 1925, vol. 116, Dec. 17, pp. 1660–1664; Dec. 31, pp. 1797–1800). The selection of

representative specimens, the proper design of test-pieces, and methods of loading are discussed. Proposed standard specifications and methods of testing light alloys are put forward by the author.

R. James, *Presidential Address to the East Glamorgan Association of Students* (Proceedings of the South Wales Institute of Engineers, 1926, vol. 42, pp. 79–116). A discussion of the strength and behaviour of different types of wire ropes.

Wrought Iron v. *Steel* (Iron and Coal Trades Review, Feb. 16, 1926, vol. 112, pp. 345–346). A report of a discussion which took place before the Staffordshire Iron and Steel Institute on Feb. 16, 1926, on the relative merits of wrought iron and steel. According to G. T. Astbury, in many cases where steel was used iron would give better service, and many of the properties of wrought iron were not sufficiently recognised and utilised by engineers. Wrought iron resisted corrosion better than steel. The merits of steel were put forward by T. W. Ellett, who pointed out that the strength and ductility of iron bars and sections were affected considerably by machining, which gave steel an advantage for such work, as it is not appreciably affected by the removal of its skin. As the elasticity of steel is superior to that of iron, steel shows great advantage over iron for most structural purposes.

J. A. Capp, *Checking Mechanical Design in the Physical Laboratory* (American Machinist (European Edition), Nov. 21, 1925, vol. 63, pp. 621–623). The article describes mechanical tests applied to finished products, and shows how much information may often be thus obtained. This is particularly the case where parts are complicated in shape or are made of several materials.

P. Chevenard, *A Mechanically Recording Differential Dilatometer* (Revue de Métallurgie, Mémoires, Feb. 1926, vol. 23, pp. 92–99). The paper describes the construction and use of the dilatometer. The dilatation of the specimen is compared with that of a standard made of a nickel-chrome-tungsten alloy. The movements of the ends of the specimen and standard are magnified by levers which control the recording pen. The table carrying the recording chart is caused to move backwards and forwards, so as to allow freedom of movement for the pen; it is controlled by a nickel-chrome-iron wire which expands and contracts as an electric current is switched on and off by the movement of a lever connecting the end of the wire to the chart table.

P. Chevenard, *New Dilatometers* (Paper read before the Société Française de Physique, Nov. 20, 1925). A description of four dilatometers used for various purposes in the author's laboratories at Imphy. Three make the records photographically, and the fourth by mechanical means.

S. P. Rockwell, *The Rockwell Dilatometer* (Machinery, Nov. 19, 1925, vol. 27, pp. 229–231). A description of the apparatus, and its use for the determination of the correct hardening temperatures of

steel, by indicating and recording the dimensional changes of the material during the decalescence period. The causes of failure in hardening, of cracking, and soft spots are discussed.

H. Esser and P. Oberhoffer, *A New Universal Differential Dilatometer* (Stahl und Eisen, Feb. 4, 1926, vol. 46, pp. 142–147). With the aid of this instrument the dilatometric, the magnetic, and the electric properties (conductivity and thermo-electric force) can be investigated at temperatures up to 1100° C. An illustrated description of the apparatus is given.

F. Stäblein, *A Simple Dilatometer for High Temperatures* (Stahl und Eisen, 1926, vol. 46, pp. 101–104). A new design of apparatus for measuring the expansion of metals under heating is described. Examples are given of its use for plotting the expansion curves of hypo- and hyper-eutectoid steels.

O. E. Harder, R. L. Dowdell, and A. C. Forsyth, *Dilatometric Method of Heat Treatment* (Transactions of the American Society for Steel Treating, Mar. 1926, vol. 9, pp. 403–419). The authors describe a dilatometer and a dilatometric heat-treating furnace which have been constructed for use in their investigation of the dimensional changes of cast-iron and steel during heat treatment. The furnace is of the electrically heated type with a heating element of nickel-chromium wire. A push rod, of invar or any material with a low coefficient of expansion, rests on the steel to be treated, and operates the movable plunger of an indicator, such as an Ames dial, which measures the expansion to one-thousandth of an inch. The dilatometer is of somewhat similar type to the one used by Andrews (Journal of the Iron and Steel Institute, 1920, No. I. p. 527).

F. L. Barrow, *A Single-Lever Extensometer* (Engineering, Oct. 23, 1925, vol. 120, p. 510). A brief description of a cheap, simple, but accurate form of extensometer recently devised to carry out tests under the Building Research Board of the Department of Scientific and Industrial Research. Although originally intended for cement testing, it is perfectly adaptable to any solid body having two approximately parallel faces.

P. Hidnert and W. T. Sweeney, *Thermal Expansion of Tungsten* (United States Bureau of Standards, 1925, Scientific Paper No. 515). The authors give the results of an investigation on the thermal expansion of tungsten (99·98 per cent.) over various temperature ranges between − 100° and + 500° C. A summary of the available data obtained by previous observers is included.

S. Sato, *Dilatometric Investigation of the A3 and A4 Transformations in Pure Iron* (Science Reports of the Tôhoku Imperial University, 1925, vol. 14, pp. 513–527). In the case of pure iron, during heating, the A4 transformation is accompanied by an expansion, and the A3 transformation by a contraction; during cooling these changes are reversed. The ratio of the magnitudes of the change of length due to the A3 and A4 transformations is about 10 : 3. The thermal dilatation

curve of δ-iron forms the continuation of that of α-iron, showing that δ-iron is of the same phase as α-iron.

F. Stäblein, *Dilatation of Iron and Steel* (Stahl und Eisen, Jan. 25, 1926; Engineering, Mar. 26, 1926, vol. 121, p. 395).

Magnetic Properties of Iron and Steel.—F. Stäblein, *Permanent Magnets* (Stahl und Eisen, Oct. 22, 1925, vol. 45, pp. 1787–1788). The author presented magnetisation curves and models showing the lifting power of a number of permanent magnet steels—namely, 1 per cent. carbon steel, 2 per cent. chrome steel, 5 per cent. tungsten steel, and 10, 20, and 30 per cent. cobalt steels, the latter being new developments. The author also described various apparatus for testing permanent magnets. In conjunction with the above curves, the "demagnetisation line" for any shape of magnet can be used to show which steel will give the best results in that particular shape; the steel whose curves cut the demagnetisation line at a point corresponding to the greatest induction is the one to be used.

E. H. Schulz and W. Jenge, *Heat Treatment and Testing of Chromium Magnet Steel* (Stahl und Eisen, Jan. 7, 1926, vol. 46, pp. 11–13). Chromium magnet steel is much more sensitive than tungsten steel to any slight changes in heat treatment. The rate of heating and the period during which the material is held at the quenching temperature are two most important factors. A table is given showing the effect of the heating period on the magnetic properties of a steel with 1 per cent. carbon and 2 per cent. chromium, the quenching temperature being 800° C. The remanence falls regularly as the time is longer (from 10,700 B after heating for two minutes to 9800 B after thirty minutes). The coercive force rises to a maximum on heating for ten minutes, and thereafter falls regularly. These changes appear to be dependent on the initial state of fineness of division of the carbide and the time taken for the carbide to pass into solution after passing the Ac1 point. Suggestions are made for the practical determination of the correct hardening treatment. From the chemical composition of a magnet steel definite conclusions cannot always be drawn as to its magnetic behaviour.

T. Spooner, *The Properties and Testing of Magnetic Materials. Effect of Heat Treatment* (Electric Journal, 1925, vol. 22, p. 610). The hysteresis loss in rolled sheets may be reduced by annealing and the permeability increased. Oxidation, which tends to reduce induction permeability, may be lessened by covering the sheets and by the use of a reducing atmosphere. It is indicated that ageing is entirely a temperature effect, and is the percentage increase in iron losses for 60 cycles and a maximum induction of 10 kilogausses after the material has been subjected to a temperature of 100° for 600 hours. The changes in structure that occur in carbon and alloy steels at various temperatures are discussed, and induction and hysteresis data for carbon steels quenched in water and in oil are included.

J. Würschmidt, *The Magnetic Properties of Nickel Steels* (Kruppsche Monatshefte, 1925, vol. 6, Nov., pp. 226–232; Dec., pp. 241–248). Following upon his review of the work of previous investigators, the author has carried out a research with the object of determining the magnetic behaviour, at room temperature or at any higher temperature, of nickel steels of known composition and after any given heat treatment. The range of nickel steels whose magnetic properties were investigated was from a 0·03 up to a 94 per cent. nickel steel. Complete magnetisation curves of these steels were plotted.

E. Gumlich, *Recent Advances in Ferromagnetic Materials* (Stahl und Eisen, Oct. 22, 1925, vol. 45, p. 1788). The author describes the essential features of magnetically soft materials and the difficulties in the way of attaining them. He describes some of the soft irons manufactured by different processes, and enumerates their good and bad qualities. Among the alloy steels he mentions iron-manganese and iron-nickel, and indicates their particular uses. Some of the permanent magnet steels are expensive, and he gives in several cases substitute alloys which, while having similar properties, are very much cheaper.

E. D. Campbell and H. W. Mohr, *The Specific Resistance and Thermo-Electromotive Potential of Some Steels Differing only in Carbon Content* (Paper read before the Iron and Steel Institute, June 1926: this Journal, p. 375).

E. D. Campbell, *A Study of the Correlation of the Remanent Magnetism and Specific Resistance of Some Pure Iron-Carbon Alloys* (Paper read before the Faraday Society, Nov. 16, 1925). The object of the investigation was to determine certain magnetic properties of a freshly hardened and a slightly tempered series of pure iron-carbon alloys as measured by means of a special magnetic balance, and to compare these values with the specific resistance of the hardened bars and also with the similar magnetic properties and specific resistance of very pure electrolytic iron. The specific resistance increases almost proportionally to the carbon content. The magnetic resistance increases more slowly than the specific resistance up to the eutectoid concentration, but more rapidly in hypereutectoid samples. The internal magneto-motive potential increases rapidly with carbide concentration up to 0·6 per cent., after which there is little or no further increase.

W. H. Dearden and C. Benedicks, *Magnetic Changes in Iron and Steel Below* 400° *C.* (Paper read before the Iron and Steel Institute, June 1926: this Journal, p. 393).

J. A. Mathews, *Retained Austenite—A Contribution to the Metallurgy of Magnetism* (Transactions of the American Society for Steel Treating, Nov. 1925, vol. 8, pp. 565–588. See also Journal of the Iron and Steel Institute, 1925, No. II. pp. 299–312).

J. H. Andrew, M. S. Fisher, and J. M. Robertson, *Some Physical Properties of Steel and their Determination* (Proceedings of the Royal Society, Jan. 21, 1926, vol. A110, pp. 391–422). The authors describe methods

of measuring electric resistance, electrode potential, and the continuous change of resistance during tempering. The change from martensite to granular pearlite proceeds gradually, only reaching a certain stage at each temperature. Martensite does not form at constant temperature during tempering, but results from the decomposition of austenite during cooling from the tempering temperature. The rate of tempering of martensite is not affected by the addition of special elements in moderate amounts, but austenite tempers more slowly, and its rate of tempering is considerably lowered by adding special elements.

E. M. Deloraine, *A New Iron-Nickel Alloy with High Magnetic Permeability* (Journal de Physique et le Radium, Jan. 1925, vol. 6, pp. 20–28). A description of the manufacture of permalloy from Swedish iron and commercially pure nickel, its properties and uses. The importance of the correct adjustment of the temperature and rate of cooling during manufacture, and the large effect of mechanical treatment upon the magnetic properties, are pointed out.

D. Binnie, *The Magnetic Properties of Permalloy* (Journal of the Royal Technical College, Glasgow, Dec. 1925, No. 2, pp. 5–7). The magnetic properties of permalloy are compared with those of soft iron by means of a diagram showing hysteresis cycles, obtained by plotting magnetising force against intensity of magnetisation.

Metallography, Crystallography, and Constitution.—F. F. Lucas, *Introduction to Ultra-Violet Metallography* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926: Iron Age, Feb. 25, 1926, vol. 117, pp. 555–557). The author discusses the application of ultra-violet light to photomicrographic work and describes the equipment used. The ultra-violet microscope is the most complicated within the realm of technical or scientific microscopy. It requires a highly developed technique for its successful manipulation, and the specimens must be prepared with great care. The ultra-violet equipment appears to have a potential resolving ability of the order of about twice that of the apochromatic system. Ultra-violet light has selective properties which should help to identify structures. It appears that certain constituents of hardened steel, for example, absorb ultra-violet light more readily than do other constituents.

F. F. Lucas, *High-Power Metallography—Some Recent Developments in Photomicrography and Metallurgical Research* (Journal of the Franklin Institute, Feb. 1926, vol. 210, pp. 177–216). High-power metallography as presented in this paper consists of so preparing the specimens that crisp, brilliant images may be obtained at high powers, and of achieving approximately the potential resolving possibilities of splendid objectives. The author applies high-power metallography to the study of the decomposition of austenite to pearlite in a 0·5 per cent. plain carbon steel, and to the examination of nodular troostite, and of the effects of cold-work and regranulation.

F. F. Lucas, *Recent Developments in Metallurgical Research. New*

Facts Developed by High-Power Metallography (Journal of the Royal Microscopical Society, 1925, pp. 393–404).

C. A. F. Benedicks, *Some Improvements in High-Power Micrography* (Royal Technical College Metallurgical Club Journal, Glasgow, 1926, No. 5, pp. 7–16). The author has studied some of the factors involved in high-power micrography, using a Bausch and Lomb metallurgical microscope in the investigation. The first condition necessary for obtaining high-power photomicrographs is that the instrument should be sufficiently well protected against vibration. The microscope should be supported not by the levelling screws at the bottom of the instrument, but in a plane passing approximately through the sensitive part (near the objective holder). The centre of gravity of the system should be raised so as to coincide approximately with the suspension plane. By the combined use of the vibration-proof mounting and a suitable oblique epiphragmatic illumination a remarkable definition of the image was attained. It is shown that the useful magnification obtainable with an objective of numerical aperture 1·30, using $\lambda = 0{\cdot}0053$, is about 1500 diameters. An image-limiting diaphragm should always be used in a metallographic microscope, as it has the effect of screening off diffused light from external sources.

Steel Magnified 15,500 *Diameters* (Machinery, Feb. 11, 1926, vol. 27, pp. 643–644). A brief description, with illustrations, of the ultra-high-power microscope developed by R. G. Guthrie of Chicago, with a few examples of its application to practical problems.

E. C. Groesbeck, *Metallographic Etching Reagents* (United States Bureau of Standards, 1925, Scientific Paper No. 518). This report describes an investigation the objects of which were to obtain experimental data on the behaviour towards various etching solutions of constituents commonly occurring in alloy steels and ferro-alloys, such as iron, chromium, tungsten, and vanadium carbides, iron tungstide, and the complex constituent usually found in high-speed steel. The underlying principles which govern the behaviour of these constituents to the various solutions were deduced, and methods for identifying one or more of these constituents were developed. Three etching methods—(*a*) etching by immersion, (*b*) electrolytic etching, and (*c*) heat tinting—were employed in the investigation. Etching with acidic solutions offers no means of distinguishing between any of the constituents. The use of alkaline reagents under oxidising and non-oxidising conditions furnishes, however, the desired differentiation between certain of these constituents. Two distinct etching effects are obtained with alkaline solutions by immersion: (*a*) a chemical attack of the constituent by the alkali, and (*b*) the oxidation of the constituent by nascent oxygen formed in the solution. Similar effects are obtained by electrolytic etching with solutions of weakly dissociated acids, both alkaline and metallic salts of these acids, and alkalis, although the nascent oxygen is derived from different sources: (*a*) a secondary reaction between the acid formed in the first stages of the electrolysis

and water, and (*b*) by discharge of hydroxyl ions on the anode (specimen). A differentiation of the various constituents is thus made possible. The heat-tinting method offers no means of distinguishing the various constituents, excepting iron carbide, from one another. A brief review of the literature on the equilibrium diagrams of the binary and ternary alloy systems formed by chromium, tungsten, vanadium, or molybdenum with iron or carbon, or both, and also on the nature of the constituents found present in alloy steels and ferro-alloys, is included.

J. R. Vilella, *Delving into Metal Structures* (Iron Age, 1926, vol. 117, Mar. 18, pp. 761–763; Mar. 25, pp. 834–836; Apr. 1, pp. 903–907). A series of three articles describing new etching reagents and methods of polishing. The first article deals with the effect of aqua regia in glycerine as an etching medium for chrome iron alloys. The second article deals with the use of chromic acid plus hydrochloric acid as an etching medium for certain copper alloys, and the third article gives a brief critical review of the etching reagents most widely employed for etching aluminium and its alloys, and describes the application of aqua regia in glycerine in a manner similar to that used for etching chrome iron alloys.

W. Rosenhain, *Metallography for Engineers* (Metallurgist, 1925, Oct. 30, pp. 155–157; Nov. 27, pp. 168–171). The last two of a series of articles which had appeared previously (see Journal of the Iron and Steel Institute, 1925, No. II. p. 498). Parts VIII. and XI. deal with the subject of failures and defects, and indicate to the engineer the kind of evidence which can be obtained by an examination of such breakdowns and faults, what is necessary to make the investigation complete, and the meaning of the "clues" when once they have been found. The articles have been written from the special point of view of the engineer.

H. C. Knerr, *Heat Treatment and Metallography of Steel* (Forging, Stamping, Heat Treating, 1925, vol. 11, Sept., pp. 322–328; Oct., pp. 361–365; Nov., pp. 386–390; Dec., pp. 420–424; 1926, vol. 12, Jan., pp. 9–14; Feb., pp. 52–56; Mar., pp. 99–104). The continuation of a serial, commenced in the Oct. 1924, vol. 10, issue (see Journal of the Iron and Steel Institute, 1925, No. II. p. 462). A practical course in the elements of the physical metallurgy of iron and steel, describing all operations involved in the heat treatment of steel. The underlying theory of the practical processes of manufacture is also discussed.

J. H. Whiteley, *On the Ghost Lines and the Banded Structure of Rolled and Forged Mild Steels* (Paper read before the Iron and Steel Institute, June 1926: this Journal, p. 213).

C. Fremont, *The Silvery Oval Spot in Certain Transverse Fractures in Rails* (Génie Civil, Oct. 24, 1925, vol. 87, pp. 349–351). The oval spots seen in certain transverse ruptures of rails are the result of internal fissuration caused by inclusions, nuclei of segregation, micro-piping, and of various impurities, blowholes, &c., all defects of the metal which induce local weakness of the rail on a transverse section. This

fissuration increases on account of the shocks to which the metal is subjected, and which put it in sudden tension.

J. H. Andrew, *The Treatment and Properties of Carbon Steels* (Proceedings of the Cleveland Institution of Engineers, Session 1925–26, No. 4, pp. 99–119). The author draws attention to certain phenomena he has observed, and gives expression to a new view respecting the transformations undergone by carbon steels. That the high-temperature state with respect to iron-carbon alloys containing up to 0·89 per cent. carbon consists of mixed crystals of iron, and crystals of iron influenced by the presence of carbon atoms, and that in alloys containing between 0·89 and 1·8 per cent. carbon it consists of mixed crystals of the composition of the eutectoid and austenite, receives much confirmation from the physical data. That the eutectoid composition is a stable configuration above all critical points is supported by the fact that this composition represents the state of maximum entropy of the series, and that there is always a tendency in any system to attain that state. In order to determine whether time at heat produced a marked difference in the microstructure, specimens of 0·48 carbon steel were maintained at 1050° C.; one specimen was allowed to remain in the furnace for a quarter of an hour, and another specimen was left in for three hours. The specimens after removal from the furnace were allowed to cool in still air. The author was so impressed by the difference in the apparent carbon content of the two specimens that they were re-analysed, but were found to be of the same carbon content. An examination of the specimen which had had the shorter time at heat revealed two distinct types of sorbite grains. Some of these were small and some very large. The small grains showed that the structure was pearlitic rather than sorbitic, and that the cementite was well defined. This specimen was therefore characteristic of a state of transition—a transition from the one type of eutectoid constituent to another—whereas in the case of the other specimen the transition was completed. The reason for the non-diffusion of the cementite is suggested as follows: When the carbon is in but small amounts, the strong surface tensional forces at the grain boundaries of the ferrite are sufficient to prevent the carbide from dissociating to any marked extent at that temperature; a higher temperature evidently is required to produce the same effect in a steel very low in carbon. A cooling curve taken of the 0·48 carbon steel after heating up to 1000° C., and cooled immediately without soaking, gave the ferrite point at the normal temperature. If the steel were, however, allowed to remain at 1030° C. for three hours previous to cooling, the point occurred at a temperature 20° C. lower, showing the large effect produced by dissociation of the carbon.

W. T. Griffiths, *The Hardening of Steel: A Review and Some Comments* (Metallurgist, Mar. 26, 1926, pp. 34–36). A review of the various theories propounded to explain the phenomena of hardening found to occur in steels. The author commences with the "allotropic" and

"carbonist" theories, which held the field at the close of the nineteenth century, and deals with the later theories in chronological order, showing how the views at present held have been developed.

A. Sauveur, *The Current Theories of the Hardening of Steel—Thirty Years Later* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). In 1896 the author presented a paper dealing with the theories of hardening steel by rapid cooling. This paper was the starting-point of many subsequent papers and discussions on the same subject which led to the formation of different schools, such as the "Carbonists" and "Allotropists." As a basis for the present paper, the author sent out a questionnaire to a number of prominent metallurgists in the United States and other countries asking their opinions on the following points: (1) The nature of martensite, and what causes its hardness? (2) the conditions necessary for its formation; (3) assuming it to be a solid solution of iron and carbon, or of iron and the carbide Fe_3C, what position do the carbon atoms or the carbide molecules occupy in the space lattices of the crystals? (4) what part, if any, do strains play in the hardening of steel? As the result of a study of the replies received, the author concludes that it is not possible to formulate the prevailing view of metallurgists on the phenomena of the hardening of steel. It is generally, but not by any means universally, held that—(1) Freshly formed martensite is a solid solution of carbon or of the carbide Fe_3C in alpha-iron; (2) martensite forms, and is retained, when austenite transforms in the vicinity of 300° C.; (3) on ageing, minute particles of the carbide are thrown out of solution, converting the martensite into an aggregate; (4) the hardness of martensite is due wholly or partly to one or more of the following causes: (*a*) To its being a solid solution; (*b*) a supersaturated solid solution; (*c*) to the fineness of its grains; (*d*) to distorted space lattices; (*e*) to the presence of minute particles of the carbide; and (*f*) to internal strains.

During the past thirty years the progress made towards a solution of the problem may be summarised as follows: (1) Abandonment of the belief in the existence of beta-iron; (2) X-ray analysis of iron-carbon alloys, by which it is shown that gamma-iron has a face-centred space lattice, and alpha-iron, as well as the iron present in martensite, a body-centred space lattice; and (3) the belief that the hardness of martensite might be caused primarily by (*a*) the presence of extremely submicroscopic ferrite grains, or (*b*) the distortion of the space lattices resulting from the presence of carbon atoms in enforced solid solution. The detailed replies received from the different metallurgists in reply to the questionnaire are appended to the paper.

B. D. Enlund, *Theory of the Hardening of Steel* (Värmländska Bergsmanna-Föreningens Annaler, 1925, pp. 8–48. See also this Journal, 1925, No. I. pp. 305–314).

B. Kjerrman, *The Effect of Manganese, Silicon, and Phosphorus on the Pearlite Interval* (Transactions of the American Society for Steel

Treating, Mar. 1926, vol. 9, pp. 430–451). It is shown that the Ac1 point occurs over a range of temperatures instead of at a definite temperature in steel containing manganese, silicon, and phosphorus. The effect of these elements on the Ac1 range has been studied by the electric resistance method. Previous heat treatment, which tends toward homogeneity of structure, reduces the range caused by manganese, but does not affect the range caused by silicon or phosphorus. Manganese lowers the range, silicon raises it. This effect may be explained on the assumption that, at the same temperature, manganese and silicon are, respectively, more or less soluble in austenite than ferrite. There may result from these differences in solubility, depending on the rate of cooling at various periods, non homogeneity of the pro-eutectoid ferrite with respect to its manganese or silicon content, as well as differences in composition between pro-eutectoid ferrite and the lamellar ferrite of the pearlite. Steel sufficiently high in both manganese and silicon shows two separate ranges as determined by the resistance method.

H. Jungbluth, *The Delayed Dissolution of Granular Pearlite at the Transformation Point* (Stahl und Eisen, Nov. 19, 1925, vol. 45, pp. 1918–1919). By means of differential heating curves the delayed dissolution of granular pearlite can be visually followed. For comparison a specimen of the same steel treated to contain lamellar pearlite when heated to 1000° shows at 725° the same phenomenon reversed.

P. Chevenard, *Simple Experiments to Demonstrate the Thermal Transformations of Steels and the Anomalies of the Special Alloys* (Revue Universelle des Mines, Sept. 15, 1925, vol. 7, pp. 235–248; see also this Journal, 1925, No. II. p. 583).

H. L. Maxwell and A. Hayes, *The Free Energy and Heat of Formation of Iron Carbide for the Temperature Interval* 650° *to* 700° (Journal of the American Chemical Society, Mar. 1926, vol. 48, pp. 584–593). The authors have determined the equilibrium values for carbon monoxide and carbon dioxide with alpha-iron and iron carbide Fe_3C at 650° and 700°, and at a total pressure of one atmosphere.

H. Hanemann and A. Schrader, *On Martensite* (Transactions of the American Society for Steel Treating, Feb. 1926, vol. 9, pp. 169–239, 364). The paper opens with a review of previous investigations regarding the structure of martensite and austenite in hardened steels, their thermal expansion and critical points. The current opinion, based upon these investigations, is that martensite is alpha-iron, whose space lattice has been strained by an unstable solution of carbon within the lattice. It is pointed out by the authors that the established facts of the austenite-martensite reaction cannot be reconciled with the alpha-iron hypothesis, and they give their investigations of a new hypothesis of martensite formation called the epsilon-eta hypothesis. They conclude from their investigations that when austenite changes to martensite in quenched steel there is a change in the carbon content of the austenite and the martensite. It is claimed that besides

austenite and ordinary ferrite, two formations, epsilon and eta, are found in quenched steel, and that these two are in metastable equilibrium with the austenite. The martensite contains less carbon than the austenite, with which it is in contact. A constitutional diagram showing the lines of the metastable martensite system is given. According to the authors' hypothesis of the martensite system there is a transformation in pure iron at a certain temperature, which was found by experiment to be 685° C. Specimens of soft iron containing 0·07 per cent. carbon were used in these experiments. The paper is accompanied by numerous photomicrographs.

M. Kawakami, *On the Determination of the Heat of Precipitation of Cementite from α and β Martensites* (Science Reports of the Tôhoku Imperial University, Sendai, 1925, vol. 14, pp. 559–568). The heat of precipitation of cementite from α martensite was measured for eight kinds of carbon steel, with carbon content ranging from 0·30 to 1·32 per cent. It was found that the heat increases proportionally to the carbon content; the heat for eutectoid steel is 3·7 calories per gramme. The heat of precipitation of cementite from both α and β martensite was also measured for five kinds of carbon steel, and the results were found to coincide with those obtained by Yamada.

T. Isihara, *On the Influence of Some Elements on the Spheroidisation of Carbides in Steels* (Science Reports of the Tôhoku Imperial University, Sendai, Oct. 1925, vol. 14, pp. 377–390). The author has studied the effects of manganese, chromium, and copper on the formation of spheroidised cementite in steels. It is concluded that each of these elements has a considerable influence on the formation of spheroidal carbides. In manganese steel, the spheroidising interval of temperature above the Ac1 point is slightly increased with the amount of manganese added. In chromium and copper steels, it increases considerably with the increase in alloying elements. If the content of these elements be kept constant, the spheroidising interval remains nearly constant up to the eutectoid concentration, and then increases rapidly with the carbon content.

F. Wever, *Recent Works on the Constitution of Technical Iron* (Stahl und Eisen, Oct. 22, 1925, vol. 45, p. 1787). The author reviews the work done and the theories propounded up to the present time since Osmond first developed the idea of three separate and independent phases in iron.

S. Kaya, *On the Solidus Line in the Iron-Carbon System* (Science Reports of the Tôhoku Imperial University, Sendai, 1925, vol. 14, pp. 529–536). The author has determined the solidus line in the iron-carbon system, using the electric resistance method. The line was found by a break in the resistance-temperature curve. The solubility line of cementite into austenite was also determined by the same method, and the solubility limit was found at the intersection of the eutectic line with the solubility line of cementite. The solidus line as determined by the author lies between the curve as obtained by

Carpenter and Keeling and that of Gustowsky, and slightly below the line obtained by Asahara.

F. Wever and P. Giani, *Contributions to the Knowledge of the Iron-Silicon System* (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1925, vol. 7, pp. 59–68). Thermal and metallographic investigations make it appear probable that in the phase diagram of the binary iron-tin system the equilibrium area of the γ-phase is bounded by a single line without a triple point. That immediately assumes the conception of the identity of the two body-centred cubic modifications of iron, namely, α-iron and δ-iron. This reduces the polymorphism of iron to two modifications, one a body-centred cubic α- (β-), δ-phase, and the other a face-centred cubic γ-phase which is interposed between the areas in which the body-centred phases can exist between the temperatures 906° and 1401° C.

W. E. Ruder, *Silicon Steel* (Year-Book of the American Iron and Steel Institute, 1925, pp. 251–261). A discussion of the constitution, mechanical properties, magnetic uses, magnetic properties, and testing of silicon steel. The most important effect of silicon in the constitutional diagram is the raising of the A3 point and its disappearance at about 2 per cent. silicon, while the magnetic change point is gradually lowered from 740° C. at 11 per cent. silicon to 670° C. at 4 per cent. silicon. Carbon is retained in solution up to about 0·008 per cent. with silicon up to at least 5 per cent. Silicon steels are forgeable up to 7 per cent. silicon, but the practical limit for steel rolling is about 5 per cent. The greatest economic value of silicon steel is its use as a core material for electrical apparatus, particularly for transformers. With regard to the magnetic properties of silicon steel, the beneficial action of the silicon is due to its pronounced effect upon the resistivity, its effect in limiting the solubility of iron for carbon, and its action in promoting grain growth. The increased resistance limits the eddy currents, but the grain-size, if too great or irregular, may reverse the beneficial action of high resistance. Silicon, however, decreases the saturation value from B = 22,300 for pure iron to B = 20,200 for 4 per cent. silicon and increases the brittleness of the alloy. In transformers this brittleness is not a serious handicap. The different grades of silicon sheets produced for electrical purposes are enumerated. Hysteresis loss decreases slightly with the thickness of the sheet, while eddy current loss increases with the square of the thickness. Hysteresis losses are sensitive to mechanical strain, so that annealing is necessary to remove all strains imparted by rolling. The Epstein method of testing is now almost universally used as a standard for measuring core loss.

A. Pomp, *The Influence of Silicon on the Strength Properties of Ingot Iron at High Temperatures* (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1925, vol. 7, pp. 105–112). Tensile and notched-bar impact tests were made on iron-silicon alloys containing from 0·39 to 4·00 per cent. silicon in the temperature range 20° to

500° C. The elastic limit decreased almost proportionately to the increase of temperature, and in the alloys of higher silicon content became unobservable. The tensile strength showed a minimum at 100° C. and a sharply defined maximum at about 250° C., but with 4 per cent. silicon the tensile strength-temperature curve was irregular. Elongation and reduction of area showed maxima at about 50° C. and minima at about 250° C., except in the case of 4 per cent. silicon alloys which undergo a rapid increase of elongation and reduction of area just above room temperature. The notched-bar brittleness increased to a maximum with rising temperature and then decreased slowly, the temperature at which the increase commenced rising with the silicon content. The sequel to these results is of practical importance, because it was found that high silicon alloys, such as transformer sheets and resistance wires, which could not be cold-worked, could be quite easily worked if the temperatures were raised to from 50° to 250° C., according to the silicon content.

E. Piwowarsky, *Phosphides in Manganese Steel* (Iron Age, Feb. 18, 1926, vol. 117, pp. 482–483). An English abstract of an article which appeared in Stahl und Eisen, July 2, 1925, vol. 45, pp. 1075–1076. (See this Journal, 1925, No. II. p. 490.)

Sulphur in Steel (Metallurgist, Jan. 29, 1926, pp. 10–12). A review of the present state of knowledge concerning the reactions occurring between sulphur, iron, and manganese, and their effects upon the steel in which they take place. The researches of Levy and Schultz are referred to, and a brief account of Röhl's work is given together with his diagram for the FeS–MnS system. Arnold's experiments, in which he melted together Swedish iron and sulphur, are also quoted. While the sulphides present in steels containing normal amounts of manganese appear to be no more injurious than the average non-metallic inclusions, yet they should be reduced to the lowest possible amount.

A. E. Cameron and G. B. Waterhouse, *The Effects of Arsenic on Steel* (Paper read before the Iron and Steel Institute, June 1925 : this Journal, p. 355).

W. Watson, *Iron, Carbon, and Nitrogen* (Royal Technical College Metallurgical Club Journal, Glasgow, 1926, No. 5, pp. 33–37). A review of the literature on the influence of nitrogen in steel. A bibliography is included.

E. C. Bain, *The Nature of the Alloys of Iron and Chromium* (Transactions of the American Society for Steel Treating, Jan. 1926, vol. 9, pp. 9–32). The paper describes the development and preservation at room temperature of delta-iron solid solution. The solid solutions of chromium in iron containing less than about 14 per cent. chromium exhibit the alpha-gamma and gamma-delta transformations upon heating. The temperature for the alpha-gamma transition is raised with increasing chromium content, while the gamma-delta change takes place at a lower temperature as the chromium is increased. The temperature range for gamma-iron stability, therefore, becomes narrow

above about 10 per cent. chromium, and gamma-iron is not formed at any temperature in the alloys having much more than 14 per cent. chromium, except as influenced by carbon. In alloys richer in chromium, alpha and delta iron solid solutions are continuous and are physically identical. Delta-iron solid solutions have been preserved, by quenching, permanently stable at room temperature. Carbon acts primarily to enlarge the region of austenite formation; furthermore, it extends the region of gamma-iron formation into the richer chromium alloys. A carbon content of 0·35 per cent. produces some gamma-iron even in alloys containing 30 per cent. chromium. Both chromium and carbon render austenite more sluggish and reluctant to transform into alpha-iron upon cooling. About 12 per cent. chromium is required to preserve any appreciable austenite at room temperature after a water-quench, even with a carbon content of 0·35 per cent.

P. Chevenard, *Properties and Applications of High Nickel and Chromium Alloy Steels* (Pamphlet reprinted from Science et Industrie, 1925). An account of the work carried out in the laboratories of the steelworks at Imphy on the properties of alloy steels with high contents of nickel and chromium.

E. H. Schulz, Jenge, and Baurfeld, *Further Progress in High Duty Alloys* (Paper read before the Deutsche Gesellschaft für Metallkunde, Breslau, Oct. 1925 : Stahl und Eisen, Dec. 31, 1925, vol. 45, p. 2158). A continuation of an earlier paper (E. H. Schulz and C. W. Drescher, *Stellite and Alloys of the Stellite Class*, Zeitschrift für Metallkunde, vol. 16, 1924, Sept., pp. 337–343; Oct., pp. 382–390 ; abstract, Journal of the Iron and Steel Institute, 1924, No. II. p. 444). Further experiments had explained the effect of the rather complicated heat treatment for a cobalt magnet steel previously described, and had shown that the particular method of treatment was necessary for the complete development of all the magnetic properties. Further experiments on the structure of the stellite alloy Akrit were carried out, and it was determined that the acicular component in stellite alloys was, as had been surmised, carbides of chromium and tungsten. The rate of cooling has a profound effect on the formation of these needles, on which the cutting power of the alloy largely depends. An application of the properties of Akrit lies in its use for making dies for hot-drawing hollow steel articles. Although the initial cost is higher, the life of the dies is so much longer that their use is an economic possibility. Corrosion tests on Akrit are still in process.

W. P. Sykes, *The Iron-Tungsten System* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). The system iron-tungsten comprises : (*a*) Solid solution of tungsten in iron, 33 per cent. of tungsten being soluble at 1525° C. and 8 per cent. at room temperature ; (*b*) a eutectic at 49 per cent. tungsten, being a conglomerate of the compound Fe_3W_2 and the solid solution of tungsten in iron ; (*c*) the compound iron tungstide (Fe_3W_2) at the composition 68·7 per cent. tungsten ; (*d*) beyond this composition there may be

present, if below 1650° C., the compound + iron in tungsten solid solution; if heated above 1650° C., the iron tungstide partly decomposes into iron-rich and tungsten-rich phases; (*e*) tungsten dissolving 1·2 per cent. iron at 1600° C.

The critical point Ar4 is lowered from 1400° to 1200° C., and the point Ar3 is raised from 890° to 980° C., by the addition of 5·5 per cent. tungsten to iron. The Brinell and Rockwell hardness of iron increase continuously with the addition of tungsten in amounts up to about 50 per cent. by weight. The hardness of some of these alloys, water-quenched from 1500° C., is increased as much as 130 per cent. by ageing at temperatures from 600° to 700° C. In ageing at a given temperature the hardness reaches a maximum and then decreases as ageing is prolonged. The higher the temperature of ageing, above a certain minimum temperature, the more rapidly the hardness increases, but the lower is the maximum hardness attained. The tensile strength is affected by ageing in the same manner as the hardness; a decrease in ductility accompanies the increase in tensile strength. Development of secondary hardness in these alloys is accompanied by precipitation of the compound Fe_3W_2. The particle size of the precipitate remains submicroscopic until the hardness has passed through its maximum value and has fallen off considerably. A shrinkage in volume takes place during the ageing process and, in general, its maximum is coincident with that of the hardness produced by ageing.

F. Wever and W. Reinecken, *Contributions to the Knowledge of the Iron-Tin System* (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1925, vol. 7, pp. 69–79). The phase diagram of the binary system iron-tin has been redetermined on the basis of thermal and metallographic researches. Contrary to the earlier observations of Tammann and Isaak, the two components are taken to be completely mutually soluble in the liquid state. The phase diagram is characterised by a solid solution of tin in iron with a maximum of 18 per cent. tin, and by two compounds. These latter have been identified as Fe_3Sn and $FeSn_2$.

R. Irmann, *The Behaviour of Aluminium towards Iron at High Temperatures* (Zeitschrift für Metallkunde, Apr. 1926, vol. 18, pp. 121–122). Iron was stirred into liquid aluminium and it was found that the latter dissolved some of the former, the amount varying with the temperature, and decreasing with the carbon and silicon content of the iron. Films of oxide on the iron effected a marked reduction in the amount of iron dissolved, particularly with low-carbon iron.

T. Kase, *On the Structural Diagrams of some Special Steels* (Science Reports of the Tôhoku Imperial University, Sendai, Oct. 1925, vol. 14, pp. 453–478). The author has investigated the structural diagrams of nickel, manganese, and chromium steels by means of the scleroscope, microscope, and magnetic and dilatometric methods. Austenitic steels containing 20 to 34 per cent. nickel are transformed to martensite by immersion in liquid air, increasing the hardness and producing an

irreversible expansion. In the case of nickel steels with 8 to 10 per cent. nickel, magnetic analysis shows that the A1 transformation is a stepped change. Manganese steels are also transformed to martensite by being cooled to liquid air temperatures. Steels up to 10 per cent. of manganese become magnetic when immersed in liquid air. The effect of manganese on the hardness and the lowering of the transformation point is about twice as much as that of nickel. Iron-chromium alloys when annealed and slowly cooled cannot be hardened by being quenched in liquid air; but the iron-carbon-chromium alloys when rapidly cooled do so harden. Magnetic tests show that the A2 point of chromium alloys is decreased with increasing chromium, which is in accord with the results obtained by Murakami. Expansion temperature curves show that with steels of about 0·7 per cent. chromium the Ac13 point is gradually raised with increase of chromium.

H. Hanemann, *Contribution to the Knowledge of Recrystallisation* (Zeitschrift für Metallkunde, Jan. 1926, vol. 18, pp. 16–17). The paper describes experiments conducted to establish the relation between the resulting grain-size of recrystallisation after hot deformation and the work employed in bringing about the deformation. On plotting the relationship for steel, soft iron, and copper, the curves are found to approximate closely to hyperbolas. During the compression of the specimens some of the mechanical work is converted into heat, and the author makes use of his curves to calculate the relation between this heat and the remainder of the work, which he calls "latent" and which alone can have any effect on the recrystallisation of the test-piece. He suggests that the slip planes are the seat of the hardening and recrystallisation and of the "latent work."

G. Tammann and A. Müller, *Methods for Determining the Orientation of Crystallites in Metallic Conglomerates* (Zeitschrift für Metallkunde, Mar. 1926, vol. 18, pp. 69–74). Etch-pits and pressure figures are used to determine the orientation of the crystallites in copper, iron, and zinc.

W. E. W. Millington and F. C. Thompson, *The Practical Significance of the Inner Structure of Metals* (Transactions of the Manchester Association of Engineers, Session 1924–25, pp. 45–95).

J. H. Andrew, *The Crystalline Structure of Metals* (Journal of the Royal Technical College, Glasgow, Dec. 1925, No. 2, pp. 63–69). The author deals with some of the more theoretical aspects of the relation between crystalline structure and the physical properties of metals and their alloys. Problems concerned with the atomic structure of the crystal, and the grain boundaries in a multi-crystalline substance, are discussed.

J. H. Andrew, *The Constitution of Steels* (Royal Technical College Metallurgical Club Journal, Glasgow, 1925, No. 4, pp. 9–12).

F. Leitner, *Primary Crystallites in Chrome-Nickel Steels, the Extent to which their Size is Controllable, and the Defects Associated with their Occurrence* (Stahl und Eisen, 1926, vol. 46, Apr. 22, pp. 525–532). The influence of casting temperature and fluidity on the size of the primary

crystallites is discussed. Coarse crystallites promote local segregation of impurities and tend to bring about cavities. The defects may be remedied to some extent by heat treatment, but the adoption of a correct casting temperature is the best way of avoiding them.

H. O'Neill, *Deformation Lines in Large and Small Crystals of Ferrite* (Paper read before the Iron and Steel Institute, June 1926: this Journal, p. 417).

W. L. Webster, *Magneto-Striction in Iron Crystals* (Proceedings of the Royal Society, Dec. 1, 1925, vol. A109, pp. 570–584). Describes the apparatus used and the results obtained in some experiments on the changes which occur in the dimensions of iron crystals when magnetised. The magneto-strictive effect was found to vary according to the directions in which it was measured, and by a combination of the different effects the magneto-strictive effect in soft iron becomes explicable. A reciprocal relation between magneto-striction and the effect of stress on magnetisation was investigated experimentally, and good agreement with the values, deduced thermo-dynamically, obtained.

R. Becker, *Plasticity of Amorphous and Crystalline Substances* (Stahl und Eisen, Oct. 22, 1925, vol. 45, p. 1787). The author, in a variation of the usual explanation of a final speed of flow being due to the setting up of frictional forces, conceives the speed of flow as a manifestation of the movement of the molecules in the space lattice. This indicates at once an important connection between the speed of flow and the temperature, a relation which had not previously been well understood. Tests on single-crystal wires of tungsten confirmed this interdependence. Preliminary tests appear to indicate that in a single slip about 3000 atoms are concerned together, and that the true critical tensile strength of a single tungsten crystal is about 300 kilogrammes per square millimetre.

P. D. Merica and R. G. Waltenberg, *Malleability and Metallography of Nickel* (United States Bureau of Standards, 1925, Technologic Paper No. 281).

A. Ôsawa, *On the Relation between the Lattice-Constant and the Density of Iron-Nickel Alloys* (Paper read before the Iron and Steel Institute, June 1926: this Journal, p. 447).

L. Grenet, *Remarks on the Iron-Nickel Diagram—Irreversibility of the Crystalline Transformations—Quasi-Limiting States in the Crystallised Bodies* (Revue de Métallurgie, Mémoires, Mar. 1926, vol. 23, pp. 143–153).

T. Kasé, *On the Widmanstätten Structure in Iron-Carbon and Iron-Nickel Alloys and in Meteorites* (Science Reports of the Tôhoku Imperial University, Sendai, 1925, vol. 14, pp. 537–558). The author has determined the conditions for developing Widmanstätten structure in iron-carbon and iron-nickel alloys, and explains the origin of this structure in meteorites. Moderately rapid cooling from high temperatures (above A3 or Acm) gives this structure, but slow cooling does not produce it. It is concluded that the formation of Widmanstätten structure in meteorites may probably be due to a long exposure to a very high temperature and subsequent rapid cooling.

R. Vogel, *The Structure of Iron-Nickel Meteorites* (Zeitschrift für Anorganische Chemie, 1925, vol. 142, pp. 193–228; Stahl und Eisen, 1926, vol. 45, pp. 228–229).

W. Rosenhain, *The Inner Structure of Alloys* (Journal of the Royal Society of Arts, Oct. 23, 1925, vol. 73, pp. 1039–1052). The third Cantor Lecture delivered by the author. In it he deals with the effect of lattice distortion and its absence on the properties of metals and alloys. (For the first two lectures see Journal of the Royal Society of Arts, Oct. 9, 16, 1925, vol. 73, pp. 1000–1021, 1022–1037; abstract, Journal of the Iron and Steel Institute, 1925, No. II. p. 503.)

G. L. Clark, E. W. Brugmann, and S. D. Heath, *New X-Ray Studies of the Ultimate Structures of Commercial Metals* (Industrial and Engineering Chemistry, Nov. 1925, vol. 17, pp. 1142–1146). The monochromatic pinhole method is advanced as the most useful procedure for the examination of working and heat-treatment processes in metals. At the same time it is not intended to supplant other methods of X-ray analysis, but to give clear information which the other methods either do not, or only give in an indefinite manner. Representative X-ray photographic diagrams, mostly of iron or steel, are reproduced to show the great possibilities of the method for obtaining purely scientific information, for correlating physical properties with ultimate structures, and for controlling and improving manufacturing technique.

A. Ono, *X-Ray Examination of Inner Structure of Strained Metals* (Memoirs of College of Engineering, Kyushu University, 1925, vol. 3, pp. 267–286). The report is the fourth of the series. The investigations show that the inner structure of strained metals is equivalent to two kinds of symmetry models, which are classified according to the regularity of the crystal rearrangement.

V. E. Pullin, *X-Rays in the Examination of Metals* (Electrician, Nov. 27, 1925, vol. 95, pp. 614–616). A brief description of the apparatus used and the work done in the X-raying of metals. As a means of examination it has the great advantage that the object under test is not destroyed. Penetration up to 4 inches of steel has been attained, and there is every indication that sooner or later much greater thicknesses of metal will be brought within the scope of the rays. A certain amount of work has been done on the problem of making stereoscopic photographs of flaws in metals in order that their depth as well as their outline may be gauged.

P. D. Foote, *The Relation between Metallurgy and Atomic Structure* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1926). Most of the treatises on metallurgy intimate that simultaneously with the development by the atomic physicist of a really satisfactory theory of the atom will be inaugurated a new epoch in the science of metals. Up to the present time the study of atomic structure has been primarily devoted to the investigation of the outer groups of electrons of atoms in the vapour phase; to the study of the inner electron groups which are ineffective chemically and in general

physically; and to experimentation on the nuclear sun, the precise structure of which plays no direct rôle in a theory of the solid state. The science of metallurgy is concerned essentially with the solid or liquid phases of matter, with the properties of atomic clusters forming molecular compounds and crystals. Most of these properties are mainly due to the outer group of electrons in an atom. The outer structure of an atom or molecule is quite different from that in the solid; consequently it is very difficult to make quantitative predictions for the behaviour of a solid from theoretical and experimental observations on the isolated or vapour atom. Recent progress is described in the paper in certain phases of atomic physics which appear to offer possibilities for the extension of our conceptions of the isolated atom to the solid and liquid states of matter. The quantum theory of atomic structure is discussed. Tables are presented showing the complete arrangement of the electrons in the ninety-two elements, and systematic representations of the elementary cell of different types of cubics are given graphically. A discussion follows on the lattice structure of metals and on photo-electric and other phenomena. The author concludes that up to the present the theory of atomic structure has contributed little of a definite nature to the knowledge of the solid state.

A. Smekal, *The Influence of Pores in Solids on their Molecular Movements and Strength* (Stahl und Eisen, Oct. 22, 1925, vol. 45, p. 1786). In place of the usual hypothesis that the atoms or ions of solid bodies move within the space lattices, the author puts forward a new idea, according to which every crystal is considered as intersected by a system of fissures. The boundaries of the inner fissures or pores are assumed to be oriented in the manner of lattices. The author is able on these lines to explain certain anomalies which have not been reconciled to the classical space-lattice theory.

M. S. Fisher and J. M. Robertson, *Graphite and Cementite* (Royal Technical College Metallurgical Club Journal, Glasgow, 1925, No. 4, pp. 23–29). Since the introduction of X-ray analysis, the trend of modern opinion has been towards the conception of carbon, as atomic carbon, in solution. The authors show that whatever may be the state of carbon in solution, it can separate, under appropriate conditions, as graphite or cementite, and that, once deposited, cementite does not appear to break down directly into graphite.

T. Neeff, *X-Ray Investigation of Metals* (Zeitschrift für Technische Physik, 1925, vol. 6, pp. 208–216, 250–258). A discussion of the various factors to be taken into consideration in investigating defects in metal masses by means of X-rays.

A. Sacklowski, *X-Ray Examination of Some Alloys* (Annalen der Physik, 1925, vol. 77, pp. 241–272). The experiments described are chiefly on non-ferrous metals and their alloys.

Rustless Steels.—W. H. Hatfield, *Chromium-Nickel Rustless Steel* (Metallurgist, Oct. 30, 1925, pp. 151–154). An account of the chemical

and physical properties of this alloy steel, which contains 18 per cent. chromium, 8 per cent. nickel, and carbon under 0·20 per cent. The material, known as Staybrite, presents certain peculiarities: it is not resistant to sulphuric acid at elevated temperatures, but if as little as 5 per cent. of nitric acid be added to 60 per cent. sulphuric acid, twenty-four hours' treatment at 110° C. causes a loss in weight of only 0·7 milligrammes per square centimetre of exposed surface. Increasing the nitric acid concentration does not increase the power of attack of this "mixed acid." In the fully softened condition the alloy is practically non-magnetic, but cold-work materially affects this property. Dr. Westgren of Stockholm carried out X-ray investigations and showed that the cold-work caused a change in the phase of the iron. The steel is in the austenitic condition and is easily manipulated in the cold, and besides rolling and drawing well it can be cold-pressed with ease.

W. H. Hatfield, *The New Rustless Steel* (Paper read before the Sheffield Trades Technical Society, Nov. 19, 1925). The author describes the properties of Staybrite steel, and discusses the problems arising in the fabrication of various articles from this steel. The steel contains about 18 per cent. chromium and about 8 per cent. of nickel. It possesses a high degree of ductility, and is rendered extremely soft and ductile if heated to a high temperature and quenched. It can be readily worked either hot or cold.

W. H. Hatfield, *Corrosion-Resisting Steels* (Paper read before the Institution of Engineering Inspection: Iron and Coal Trades Review, Nov. 20, 1925, vol. 111, pp. 830–831). The author discusses the influence of modified composition of steels upon their resistance to various corroding media, and gives details of corrosion tests on a series of steels of varying chromium content, and another series with varying nickel content. The mechanical properties of the following five steels are also discussed: (1) 12 to 14 per cent. chromium steels as used for cutlery and allied purposes; (2) 12 to 14 per cent. chromium steels as used for turbine blading and general engineering purposes; (3) 12 to 14 per cent. chromium steels of medium tensile strength; (4) 12 to 14 per cent. chromium steel, sometimes known as stainless iron; and (5) 18 per cent. chromium and 8 per cent. nickel steel (Staybrite).

D. G. Clark, *Recent Developments in Stainless Steel* (Year-Book of the American Iron and Steel Institute, 1925, pp. 262–299). The paper opens with a résumé of the history of stainless steel, an account of the patent situation in America, followed by a brief discussion of processes of manufacture. The main portion of the paper is devoted to a discussion of the properties, treatment, and uses of the different types of stainless steel.

J. Haas and E. R. Unruh, *Plating on Stainless Steel* (Metal Industry, Dec. 4, 1925, vol. 27, pp. 533–534). Much difficulty has been experienced in the past in plating stainless steel; the authors are unable to explain this, but suggest it is in some way connected with passivity. The

experiments carried out by the authors have shown that best plating results are obtained by treating the stainless steel articles first in an electric acid dip until a vigorous evolution of hydrogen takes place. Cyanide was found to have a very detrimental effect, the deposits of copper, for instance, being badly blistered and non-adherent, although plated under conditions that were entirely satisfactory for use with high-carbon steels.

Some Special Steels (Engineer, Apr. 9, 1926, vol. 141, pp. 407–408). Some notes on the special steels, based on nickel-chromium alloys, manufactured by Messrs. Hadfields Ltd., and their application to parts where resistance to heat, oxidation, and corrosion is specially desirable. The rotor of an exhaust gas turbine is illustrated; this has been run up to a speed of 53,000 revolutions per minute, giving a peripheral velocity of some 2200 feet per second, and working at a temperature between 800° and 900° C. It was made of "Era A.T.V." steel. Another steel of this class serves admirably for such articles as the racks for holding leaf springs in hand-worked furnaces; a photograph shows the excellent condition of such a rack after nine months' use at a working temperature of 900° C., in comparison with the bad state of repair of a similar mild cast steel rack after twelve weeks under the same conditions. The properties of "Hecla A.T.V." steel are also described. This steel was originally produced for the manufacture of blades and nozzles of steam turbines; its resistance to corrosion and erosion does not depend on the finish imparted to the surface.

Acid-Resisting Alloys.—*High Silicon Iron in the Chemical Industries* (Metallurgist, Mar. 26, 1926, pp. 44–45). A few notes on the physical and chemical properties of silicon irons carrying about 14 per cent. of silicon. A table of results obtained with one make of high silicon iron by the American Society for Testing Materials is given.

Corrosion.—W. G. Whitman and E. L. Chappell, *Corrosion of Steels in the Atmosphere* (Industrial and Engineering Chemistry, May 1926, vol. 18, pp. 533–535). Mistakes in the rapid testing of metals for atmospheric corrosion are apt to be recorded on account of the introduction of some accelerating factor not present under normal conditions. A simple method of testing is described in which the primary accelerating influence is moisture, and the validity of the test has been proved by the agreement of the experimental results with those of long-time service tests. The authors also believe that the proper preparation of the samples by previous corrosion has an important effect on making the rapid tests reliable.

W. Kistiakowsky, *Rusting of Iron* (Zeitschrift für Elektrochemie, 1925, vol. 31, Dec., pp. 625–631). A general consideration of the phenomena attending the corrosion of iron from the physical and chemical aspects of the process.

H. Y. Carson, *Cast-Iron Pipe* (Blast-Furnace and Steel Plant,

Aug. 1925, vol. 13, p. 335). The disadvantage of cast-iron pipes for carrying water is that they corrode and may in time become practically choked with rough lumps of rust called tubercles. The company with which the author is associated now make cast-iron pipes lined with Portland cement. The pipe is rotated about its axis in a horizontal position, and a rich mixture of cement is distributed over its inner surface. Rotation at a higher speed for twenty-five seconds makes the lining more dense and adherent.

J. R. Baylis, *Natural Water Corrosion and H-Ion Concentration* (Chemical and Metallurgical Engineering, Nov. 1925, vol. 32, pp. 875–876). A few notes and experimental results obtained by the Principal Sanitary Chemist of the Baltimore Water Department during researches on the corrosion of iron pipes. The author favours the electrochemical theory of corrosion.

J. R. Baylis, *Factors other than Dissolved Oxygen Influencing the Corrosion of Iron Pipes* (Industrial and Engineering Chemistry, Apr. 1926, vol. 18, pp. 370–380). An investigation into the corrosion of iron pipes by the water of the Baltimore public supply.

R. Davis, *A Special Camera for Photographing Cylindrical Surfaces* (United States Bureau of Standards, 1926, Scientific Paper No. 517). The paper describes a camera designed to photograph the entire outside surface of short lengths of pipe which have been subjected to soil corrosion tests. The pipe is rotated by means of a belt driven by a pulley which also shifts the film. The film moves at a speed equal to the image velocity of the pipe. An automatic switch stops the camera after the complete surface of the pipe has been photographed. The general design is applicable to the photographing of other cylindrical objects.

O. Bauer, *The Chemical and Physical Mechanism of Rusting and Corrosion* (Gas und Wasserfach, 1925, vol. 68, pp. 683–687, 704–707, 715–719). A general review and discussion of the subject.

O. Bauer, *The Rusting of Iron in Water, and Aqueous Salt Solutions* (Mitteilungen aus dem Materialprüfungsamt, Berlin-Dahlem, No. I., 1926, pp. 11–14).

O. Bauer, O. Vogel, and K. Zepf, *The Behaviour of Iron, Bronze, and Brass in the Presence of Salts and Salt Mixtures in Alkaline Waters at Ordinary Temperatures and at the Temperatures and Pressures usual in Boilers* (Mitteilungen aus dem Materialprüfungsamt, Berlin-Dahlem, No. I., 1925, 62 pp.). The report gives the results of a very exhaustive series of corrosion tests on steel sheets (carbon 0·05, phosphorus 0·020, and sulphur 0·047 per cent., with small amounts of copper, nickel, and chromium), on brass and bronze sheets at ordinary temperatures, and on experimental boilers under steam pressures up to 16 atmospheres. The solutions used included magnesium chloride, sodium chloride, magnesium sulphate, sodium sulphate, and mixtures of these; also potash lye and certain river waters purified and not purified. The results are fully tabulated in twenty-six tables.

F. H. Rhodes and J. D. Carty, *Corrosion of Certain Metals by Carbon Tetrachloride* (Industrial and Engineering Chemistry, 1925, vol. 17, pp. 909–911). Of a number of metals exposed to dry pure carbon tetrachloride at room temperature, steel was the only one which was appreciably affected, the bright steel surface becoming coated with an adherent brown film.

R. Girard, *Action of Sodium Chloride on Ferrous Metals* (Comptes Rendus, 1925, vol. 181, pp. 552–555). Plates of steel with carbon 0·42 per cent. and three kinds of cast-iron were immersed in sodium chloride solution (20 grammes to the litre). In air-free solutions corrosion of all the specimens occurred uniformly and regularly for 272 days. In aërated solutions the steel lost weight regularly, and the metal was deeply scored. The cast-iron plates behaved similarly for a month and the daily corrosion fell to a minimum. At the end of four months the corrosion had regained its original speed, attaining a steady rate. The reason for the difference in the behaviour of the cast-iron is that the ferric compounds formed as the result of corrosion adhere more strongly to the cast-iron than to the steel, giving a partial protection against corrosion.

A. L. McAulay and F. P. Bowden, *An Investigation of the Effect of Differential Aëration on Corrosion by Means of Electrode Potential Measurements* (Journal of the Chemical Society, Nov. 1925, vol. 127, pp. 2605–2610). Iron and zinc were the two metals examined, and it was found that their surfaces could exist in two normal states—one a more electro-negative state, characteristic of pure metal and corroded regions, the other a less electro-negative state, characteristic of aërated regions. The difference in single electrode potential between these two conditions is 75 millivolts for zinc and about 200 millivolts for iron. Drastic treatment, by heavy corrosion in the first case and heavy oxidation in the second, causes these potentials to become more negative and more positive respectively. The drastically treated surfaces are visibly corroded and, in the case of zinc, do not change their condition without further drastic treatment. When sheets of the metals were partly immersed in $N/10$ sodium chloride solution, their surfaces after twenty-four hours presented the following four zones: (*a*) unwetted by the solution; (*b*) zone over which the liquid had crept, well aërated; (*c*) zone beneath, but close to the surface of the solution, also well aërated; (*d*) a zone at greater depths deficient in aëration. Zones (*a*), (*b*), and (*c*) were bright, and (*d*) was more or less badly corroded.

A. J. Allmand and R. H. D. Barklie, *The Influence of Alternating Currents on the Electrolytic Corrosion of Iron* (Paper read before the Faraday Society, Jan. 21, 1926). The corrosion of iron in alkaline solutions by direct current, alternating current, and by alternating current superposed on direct current has been investigated, and it is shown that the superposition of the two types of current causes relatively increased corrosion. A similar result is found when using typical subsoil drainage liquid saturated with carbon dioxide. The effects

of frequency, current density, and a.c. : d.c. ratio have been particularly examined. Experiments have also been carried out on the accelerating effects of added alkaline chloride on corrosion in alkaline solutions.

T. Fujihara, *The Nature of the Protective Film of Iron* (Paper read before the American Electrochemical Society, Apr. 1926). When a drop of water is placed on iron having a polished surface, there will appear an uncorroded rim on the outside of the drop. This is due to a protective film which is produced at that portion. The author concludes that this film consists of soluble ferrous hydroxide, which is alkaline. The protective effect of this film would be pronounced if carbon dioxide were excluded from the air under which iron is corroding.

T. Fujihara, *Rôle of Carbon Dioxide in Corrosion of Iron* (Chemical and Metallurgical Engineering, Oct. 1925, vol. 32, pp. 810–811). Additional experimental evidence is advanced to prove that the main function of carbonic acid in the corrosion of iron is the removal of the first-formed film of ferrous hydroxide.

T. Fujihara, *Passivity of Iron by Dilute Nitric Acid* (Industrial and Engineering Chemistry, Jan. 1926, vol. 18, pp. 62–63). Experiments were made in which commercially pure iron was etched with alcoholic nitric acid solution, and then tested for atmospheric corrosion. The alcoholic nitric acid produced passivity in the iron, resembling chromic acid in this respect.

Report of Committee A5 on Corrosion of Iron and Steel (Proceedings of the American Society for Testing Materials, 1925, vol. 25, Part 1, pp. 95–117). Consists of reports of various sub-committees. The results of total immersion tests, a proposed specification for zinc-coated or galvanised wire, and a method for carrying out exposure tests of metal-coated products are included.

M. E. McDonnell, *The Rust-Proofing of Materials* (Mechanical Engineering, Nov. 1925, vol. 47, pp. 875–880). The Pennsylvania Railroad is now using copper-bearing steel for car roofs and goods vans. It would appear that the coating of rust which first forms, when copper is present in the steel, is more dense and coherent, and so gives greater protection to the metal underneath. Details are given of tests made. The remainder of the article deals with the painting of railroad cars and the rapid drying of the paint by a baking process.

Electrolytic Scale Prevention (Blast-Furnace and Steel Plant, Oct. 1925, vol. 13, pp. 414–415). The older method of placing slabs of zinc or steel, which were to protect the boiler or condenser by their own galvanic action, inside the vessel to be safeguarded is now known to be inadequate. The slabs soon become coated with oxide and then fail in their duty. The external application of a small direct current through the slab to the boiler shell, *via* the water, converts the whole into a huge electrolytic cell, and the boiler is protected at the expense of the slabs or anodes. The evolution of hydrogen on the boiler surface also serves to dislodge scale, thereby increasing the economy of the plant.

G. E. Woodvine and A. L. Roberts, *The Influence of Segregation on the Corrosion of Boiler Tubes and Superheaters* (Paper read before the Iron and Steel Institute, June 1926 : this Journal, p. 219).

Protection of Steel by Coating.—J. K. Wood, *Recent Progress in Coating Steel Springs to Resist Corrosion* (American Machinist (European Edition), Jan. 23, 1926, vol. 63, pp. 981–984). Corrosion has a bad effect on all springs, but the seriousness becomes more marked in the case of small springs. Stainless steel of the ordinary chromium type is unsuitable for spring making, and furthermore requires polishing to give the best resistance to corrosion. The " molten bath " method of protecting the surface is only fairly satisfactory, and the ordinary electro-plating methods cause embrittlement of the springs, to mention only one of the disadvantages. A brief description of the Madsen process is given. The springs are pickled to clean them, and they are then made the anode in an electrolytic cell containing strong sulphuric acid, and the current is switched on. At the commencement the current density is about 30 amperes per square foot, but it falls off to zero after a few minutes ; this is believed to decarburise the steel to a very slight depth, giving an ideal " keying " type of surface for the adhesion of the nickel, which is plated on in the next operation. The nickel electrolyte used is composed of 240 grammes of $NiSO_4$, $7H_2O$, 20 grammes of $NiCl_2$, $6H_2O$, and 20 grammes of H_3BO_3, all dissolved in a litre of water. The temperature is kept at 130° F., and the current density is 36 amperes per square foot. It is claimed that the physical properties of the steel are not affected either by the " keying " treatment or the deposition of the nickel. The Madsen process aims, in particular, at the production of a nickel coating free from the following four defects : lack of ductility, presence of carbuncles, failure after annealing or " cold-short," and the presence of pits.

J. Newton Friend, *Report on the Painting of Steel Plates* (Department of Scientific and Industrial Research : Fifth (Interim) Report on the Deterioration of Structures in Sea-Water, London, 1925, pp. 21–29). Plates of rolled steel were coated by the author with various protective paints and other materials. Each plate was curved by hydraulic pressure to an arc with a radius of 6 inches. The method of drilling the plates and pickling them before painting is described, and detailed analyses are given of the oils, petroleum, and pigments used. The precautions observed in the painting and the care taken to secure a uniform film of even thickness are explained. The arrangements made to expose the painted specimens to the action of sea-water and atmosphere are described by F. E. Wentworth-Sheilds on pp. 30–31 of the same report.

H. S. Rawdon, *Note on the Protection of Iron by Cadmium* (Paper read before the American Electrochemical Society, Apr. 1926). Because of the uncertainty as to the real order in which zinc, cadmium, and iron should stand in the electrode potential series, and the erroneous

conclusions which may readily be drawn, especially with respect to the real nature and value of cadmium coatings, the author has carried out experiments with a view of obtaining some qualitative results as to the relative potentials of the three metals, consistent with the observed behaviour of the metals in service when used as coatings on iron. Steel and iron specimens, in each of which a plug of another metal was inserted, were immersed in dilute sodium chloride solution. The results obtained show that for the conditions which obtained in carrying out the experiments cadmium stands in the same relation to iron that zinc does. The rate at which the etching of the two metals occurred in the experiments shows that the potential difference between zinc and iron in contact and immersed in sodium chloride solution is considerably greater than that between cadmium and iron under the same conditions. No conclusion regarding the single electrode potentials of the metals used—that is, their relative position in the series—seems warranted, since a possible explanation of the results obtained, on the basis of the relative dissociation of the different metal salts involved, can be shown to be valid from theoretical considerations. Results are also given for other common metals when in contact with iron and immersed in a dilute sodium chloride solution.

R. R. Danielson and W. C. Lindemann, *A Method for Testing the Cross-Bending Strength of Enamels* (Journal of the American Ceramic Society, Dec. 1925, vol. 8, pp. 795–798). Methods which have been proposed for measuring the strength of enamels, by means of impact tests, are not entirely applicable to enamelled flat ware, where the ordinary strains are due to bending of the sheets. An apparatus has been devised by means of which bending stresses can be applied in gradually increasing increments, so that the normal behaviour of enamels under such stresses can be observed and measured.

H. G. Wolfram and W. N. Harrison, *Effects of Composition on the Properties of Sheet Steel Enamels* (Journal of the American Ceramic Society, Nov. 1925, vol. 8, pp. 735–755). The effects produced by the substitution of feldspar for flint and flint for feldspar, together with variations in other constituents commonly used in enamels, were studied with reference to their resistance to mechanical shock, thermal shock, and acid attack. Tests were made on three series of enamels applied to steel plates over a standard ground coat. The enamels containing both flint and feldspar were found to be most satisfactory for general use. Enamels containing either flint or feldspar have certain excellent properties, making them more suitable for special purposes.

E. A. Atkins, *Galvanising Iron and Steel* (Paper read before the Liverpool Engineering Society, Nov. 1925: Machinery, Nov. 19, 1925, vol. 27, p. 228). The author describes in detail the coating of iron and steel with zinc by both hot- and cold-galvanising processes. In comparing the merits of the two processes the author says that the electrolytic process has the advantage of greater economy in the use of zinc, complete control over the depth of deposit, purity of

the coating, and the suitability of the method in cases where heating is objectionable. On the other hand, the electrolytic process is much slower, and it is difficult to obtain a thick, non-spongy deposit. The coating is also usually not so bright as that produced by the hot-dip method, and despite the greater care that has to be taken to get a good deposit it does not look so well as the hot-dip coat. In the latter process an iron-zinc alloy forms an intermediate layer between the two metals, but this is not the case in the electro-depositing process; the tenacity of electro-plated zinc is on this account sometimes not so good.

Galvanising an Important Operation in Range Boiler Production (Iron Trade Review, Mar. 18, 1926, vol. 78, pp. 693–696). The hot galvanising of domestic boilers and water-tanks is described and illustrated.

R. Saxon, *The Electrolytic Deposition of Nickel* (Chemical News, 1926, vol. 132, p. 4).

P. K. Frölich and G. L. Clark, *Electrolytic Deposition of Metals* (Zeitschrift für Elektrochemie, Dec. 1925, vol. 31, pp. 649–658). The first part of the article deals with the theory of the mechanism of electrolytic deposition. The second part describes an examination by three different X-ray methods of the structure of electrolytic nickel deposited from solutions of nickel sulphate and chloride containing ammonium chloride, excess of ammonia, ammonium oxalate, and to which boric acid and gelatin were added.

J. A. M. Van Liempt, *Electro-Deposition of Tungsten* (Zeitschrift für Elektrochemie, 1925, vol. 31, pp. 249–255).

H. C. Parker and W. N. Greer, *Hydrogen-Ion Control of Nickel-Plating Baths with the Quinhydrone Electrode* (Paper read before the American Electrochemical Society, Apr. 1926). The quinhydrone electrode gives not only greater accuracy in the measurement of the hydrogen-ion concentration of nickel-plating baths, but is easier and quicker to manipulate, and requires less elaborate apparatus. The apparatus required for these measurements is described and illustrated. A method has been developed for the control of the acidity of nickel-plating baths by the use of this electrode, which requires no calculations and the use of neither standard solutions nor a balance.

W. E. Hughes, *Studies on Electro-Plating. VI.—Barrel-Plating* (Metal Industry, 1925, vol. 27, July 24, pp. 71–73; Oct. 23, pp. 379–382; Oct. 30, pp. 403–405; Nov. 6, pp. 429–430; 1926, vol. 28, Jan. 22, pp. 77–79; Jan. 29, pp. 101–103). An illustrated description of barrel-plating machines and their use, with a discussion of the merits of the two types into which they may be classed. The subject is considered from every point of view, both technical and commercial, and it is shown how the choice of method should be decided. The last two articles are devoted to the practice of barrel-plating.

J. Barnden, *Notes on Electro-Plating* (American Machinist (European Edition), Nov. 21, 1925, vol. 63, p. 153E). The author puts forward

suggestions for starting up a new electro-plating plant, and gives hints and advice on the choice of plant and accommodation. He is not in favour of handing the job of installation over to a firm specialising in this work, as the new department is likely to be for evermore dependent on the outside firm every time anything unusual occurs.

Electrolytic Iron.—E. C. Kreutzberg, *Introduces Electrolytic Iron to Wider Usefulness* (Iron Trade Review, Nov. 12, 1925, vol. 77, pp. 1207–1210, 1214). An illustrated description is given of a spiral slitting machine for cutting tubes into strips, which permits of the commercial application of electrolytic iron to many new uses.

Detinning of Scrap.—C. L. Mantell, *Utilisation of Chlorine in Recovery of Tin and Tin Salts from Tinplate Scrap* (Paper read before the American Electrochemical Society, Apr. 1926). The author gives a brief discussion of the economics of the chlorine process for the recovery of tin from tinplate scrap, and its commercial adaptation. The most important conditions to be observed in this process are that all humidity must be excluded, in order to avoid corrosive action of the chlorine on the iron, and the scrap to be detinned must be absolutely clean. The most important modifications of the process are those of Goldschmidt, Sperry, Acker, and Von Schutz. A brief outline of these is given by the author. The chlorine process possesses advantages over the electrolytic method, as it can be carried out in larger units, and the detinning is more thorough. The tin is recovered in the form of tin tetrachloride, which is a valuable chemical product, extensively used in the silk-dyeing industry.

CHEMICAL ANALYSIS.

Analysis of Iron, Steel, and Alloys.—*Standard Samples* (United States Bureau of Standards, 1925, Supplement to Circular No. 25). Particulars are given of the standard samples issued or in preparation by the Bureau of Standards.

E. Schiffer, *The Determination of Carbon in Pig-Iron, Steel, and Ferro-Alloys by Combustion in an Oxygen Current* (Stahl und Eisen, 1926, vol. 46, Apr. 8, pp. 461–468).

H. Pinsl, *Determination of Graphite in Pig-Iron and Cast-Iron by Direct Weighing of the Residues* (Die Giesserei, Apr. 3, 1926, vol. 13, pp. 273–277). The method of determining graphite with the aid of direct weighing in a platinum crucible, after drying at 200° and removing the ash, gives too high values as compared with the combustion method. By a fifteen to twenty minutes' ignition in a hydrogen current at dull red heat substances causing the discrepancies are removed, and values comparable with the elementary analysis are obtainable.

R. Rimbach, *Determination of Carbon and Sulphur* (Forging, Stamping, Heat Treating, Dec. 1925, vol. 11, pp. 439, 446). A description of A. Vita's method for the simultaneous estimation of carbon and sulphur by a combustion method.

A. E. Cameron, *Determination of Arsenic in Steel* (Industrial and Engineering Chemistry, 1925, vol. 17, pp. 965–966). A simple method of determining arsenic in steel is described. With steels up to 0·25 per cent. arsenic an accuracy to within 0·01 per cent. is obtained.

H. Bösche, *The Detection of Small Quantities of Manganese in Iron and Iron Alloys* (Chemiker-Zeitung, May 2, 1925, vol. 49, p. 378). Crum's procedure, by oxidation with PbO_2 and concentrated HNO_3, gives good results, but if much iron is present the colour of the permanganate is masked. H_3PO_4 may, however, be used to decolorise the iron, leaving the permanganate colour clearly visible. 0·1 gramme of metal is dissolved in a test-tube in 10 cubic centimetres of HNO_3 (1·2 to 1·3), and the solution boiled till free from fumes. Half a gramme of PbO_2 and a few cubic centimetres of HNO_3 are added, and the boiling repeated for two minutes. The solution is allowed to settle and is "decolorised" by 0·5 cubic centimetre of 80 per cent. H_3PO_4 (specific gravity, 1·7). With very small quantities of reagents 0·002 milligramme of manganese can be detected by this method, as compared with 0·005 milligramme by the unmodified method of Crum.

T. E. Rooney and L. M. Clark, *The Estimation of Phosphorus in Steels containing Tungsten* (Paper read before the Iron and Steel Institute, June 1926 : this Journal, p. 457).

W. Manchot and F. Oberhauser, *Volumetric Determination of Iron*

in Hydrochloric Acid Solution (Zeitschrift für Analytische Chemie, 1925, vol. 67, pp. 196–197).

W. Regan, *Separation of the Elements Found in Ferro-Alloy Mixtures* (Royal Technical College Metallurgical Club Journal, Glasgow, 1925, No. 4, pp. 13–17).

K. Someya, *A Method for the Estimation of Vanadium in Ferro-Vanadium* (Science Reports of the Tôhoku Imperial University, Sendai, 1925, vol. 14, pp. 577–591).

Bodenstein, *The Estimation of Vanadium in Ferro-Vanadium, and the "Red and Green" Method* (Chemiker-Zeitung, June 9, 1925, vol. 49, pp. 479–480). The "red and green" volumetric method is described, but as the colour change is affected by the reagents present, a gravimetric method is to be preferred. The author describes such a method in which the finely ground material is attacked by means of $NaKCO_3$, the leach waters are concentrated and exactly neutralised, the vanadium is precipitated as a mercurous salt and finally weighed as V_2O_5.

K. Swoboda and R. Horny, *Determination of Cerium in Steel* (Zeitschrift für Analytische Chemie, 1925, vol. 67, pp. 386–398). The cerium is precipitated by ammonium fluoride from a very faintly acid solution in which the iron, &c., has been previously reduced. The cerium precipitate is ignited in a platinum crucible and weighed as CeO_2.

L. Jordan and J. R. Eckman, *Gases in Metals. II.—The Determination of Oxygen and Hydrogen in Metals by Fusion in Vacuum* (United States Bureau of Standards, 1925, Scientific Paper No. 514; Industrial and Engineering Chemistry, Mar. 1926, vol. 18, pp. 279–282). Experimental studies were made of methods of fusion employed in previous vacuum fusion methods. Direct fusion of low-carbon iron alloys in refractory oxide crucibles, or fusion with antimony-tin in similar crucibles, does not determine all the oxygen present in the metal. In the first case there is the additional difficulty of reduction of the refractory oxides by the carbon in the steel. In the fusion of high-carbon iron alloys this reaction between refractory oxides and carbon of the metal is very pronounced in direct fusion of the metal, and is sufficient, even in fusion with antimony-tin, to give values for oxygen in excess of the true oxygen content of the metal. Fusion of the metal sample in a graphite crucible permits satisfactory determination of oxygen in both low-carbon and high-carbon alloys. A new vacuum fusion procedure for the determination of oxygen and hydrogen in metals was developed. A sample of metal of from 20 to 60 grammes, which may be a single solid piece, thus avoiding difficulty from surface oxidation of chips, is fused in a gas-free graphite crucible in vacuum. The water vapour, carbon dioxide, carbon monoxide, and hydrogen evolved during heating and fusion of the sample are absorbed in suitable solid absorbents and determined by the increase in weight of the absorption tubes. Total oxygen and hydrogen in the sample can then be calculated. The method does not distinguish between oxygen present in the metal as CO, CO_2, oxides of non-metallic inclusions or of metallic constituents. Under the conditions of this analysis the recovery of oxygen from the

oxides of iron, manganese, silicon, aluminium, titanium, and zirconium is complete. The presence of sulphur in the iron or steel sample does not interfere with the determination of oxygen by this method. The method is applicable to the accurate determination of oxygen in pure iron, steels, cast-irons, and pig-irons, and also in many non-ferrous metals and alloys.

Analysis of Ores, Slags, and Refractories.—H. C. M. Ingeberg, *Analysis of Materials containing a Mixture of Metallic Iron and Iron Oxides* (Industrial and Engineering Chemistry, Dec. 1925, vol. 17, pp. 1261–1262). There has always been some uncertainty with many reagents which have been proposed for the separation of metallic iron from its oxides; thus copper sulphate is often suggested, but whether this reagent reacts with ferrous oxide or not depends on the reactivity of the particular sample in question. The author has attempted to surmount this difficulty by the use of potassium copper chloride, and the paper contains details of the method for evaluating the iron, ferrous oxide, and ferric oxide separately.

V. L. Eardley-Wilmot, *Molybdenum* (Canada, Department of Mines, Mines Branch, 1925, Report No. 592, pp. 193–204). This report includes particulars of methods for the analysis and testing of molybdenum and its ores.

I. Bohn, *Methods of Determining Metallic Iron and Ferric and Ferrous Oxides in Partially Reduced Iron Ores* (Jernkontorets Annaler, 1926, vol. 81 (New Series), pp. 8–20).

K. Someya, *The Use of Liquid Amalgams in Volumetric Analysis. Part III.—Determination of Phosphoric Acid by Using Lead Amalgam* (Science Reports of the Tôhoku Imperial University, Sendai, 1925, vol. 14, pp. 569–576). The author describes an accurate method of determining phosphoric acid by the use of lead amalgam.

R. G. Warren, C. T. Gimingham, and H. J. Page, *The Chemistry of Basic Slag. I.—The Determination of Fluorine in Basic Slag* (Journal of Agricultural Science, 1925, vol. 15, pp. 516–528).

O. Cantoni, *Determination of Alkalis in Silicates* (Zeitschrift für Analytische Chemie, 1925, vol. 67, pp. 33–34). The author describes the following modification of the usual method, and claims for it a considerable speeding-up of the determination. The silicate is opened up by means of hydrofluoric and sulphuric acids; the mass is then evaporated to complete dryness and heated at a dull red heat. When fumes cease to evolve the mass is cooled, boiled with water, and allowed to digest thoroughly on a water-bath. The remaining insoluble matter is filtered off and washed with boiling water; the filtrate may be somewhat cloudy, but no heed need be taken of this. The filtrate, after acidification with hydrochloric acid, is precipitated with barium chloride, and ammonia and ammonium carbonate are also at once added, vigorous stirring being continued throughout these additions. From this point the determination proceeds on conventional lines. A feature of the method is the small quantity of reagents used.

H. Schilling, *Estimation of Alumina in Refractories* (Chemiker-Zeitung, May 16, 1925, vol. 49, p. 417). The finely ground residue from the estimation of the loss on ignition is moistened with water and treated with H_2SO_4 and HF in the platinum dish to remove silica. The mass is calcined in a blast-lamp and fused with $NaKCO_3$; the minimum quantity of HCl is used to effect solution, and the liquid is precipitated while hot with ammonia. The precipitate of Al_2O_3, Fe_2O_3, TiO_2, and traces of SiO_2, is put back in the platinum dish with the filter and redissolved in hot concentrated HCl. Reprecipitation with ammonia follows, and the precipitate is washed till free from chlorine, replaced in the platinum dish and treated with H_2SO_4 and HF to remove the last of the silica. Ignition drives off the H_2SO_4 and breaks up any sulphates which might dissolve the Al_2O_3 later. The residue is weighed. Treatment with HCl leaves the TiO_2 undissolved, and the iron is estimated in the solution. The Al_2O_3 is obtained by difference.

Analysis of Fuel.—T. G. Woolhouse, *The Powell and Parr Method for the Determination of Sulphur Compounds in Coal* (Fuel, 1925, vol. 4, pp. 454–456). For the purpose of judging accuracy a number of coals having highly ferruginous ashes were examined. Some of the coal showed a theoretical value for pyritic sulphur higher than the determined value. In other coals the pyritic sulphur was lower than the determined value, suggesting that the organic sulphur had been slightly attacked by nitric acid. The method is fairly accurate, but the sulphur and iron values should be calculated.

S. Fachini, *Nomenclature, Specifications, and Methods of Analysis of Liquid Fuels* (Rassegna Mineraria, 1925, vol. 63, pp. 18–20). The methods approved by the Italian Government Technical Commission for the physical and chemical examination of aviation, automobile, and industrial fuels are outlined.

Analysis of Gas.—J. W. Whitaker, *Notes on Gas Analysis, with Special Reference to the Analysis of Mine Air* (Fuel, Oct. 1925, vol. 4, pp. 450–454). The analytical procedure in general gas analysis is outlined, and the use of the Haldane apparatus for analysis of mine air is illustrated and described.

A. C. Fieldner, G. W. Jones, and W. F. Holbrook, *The Bureau of Mines Orsat Apparatus for Gas Analysis* (United States Bureau of Mines, 1925, Technical Paper No. 320). The factors that may affect the accuracy of gas analysis are enumerated, and a description is given of the Orsat apparatus and methods of procedure in use at the laboratory of the Bureau of Mines for the complete and partial analysis of gases. The apparatus consists essentially of a 100 cubic centimetre water-jacketed burette, with a Pettersson compensating tube for correcting changes of temperature and pressure during the analysis, four pipettes and a copper oxide tube with electric heater for the differential combustion of hydrogen and carbon monoxide.

NOTICES OF RECENT BOOKS PRESENTED TO THE LIBRARY.

BARTON, L. J. "*Refining Metals Electrically.*" 8vo, pp. 414, with 59 figures in the text. Cleveland, Ohio, and London, 1926: Penton Publishing Company. (Price 30s.)

Of late years the electric furnace has found increasingly wide application in the steel foundry, and is also now being adopted for refining cast-iron after melting in the cupola. Thus a text-book dealing with electric furnace practice as encountered exclusively in the foundry is welcome. The book is written from the standpoint of the practical man, for operators and managers of electrically equipped foundries, the subject being presented in a form sufficiently simple to enable those unacquainted with electric furnace practice to study it and become familiar with the essential points. Consideration is given to the factors to be taken into account in choosing any particular type of furnace and in deciding upon the capacity, construction, and equipment of the furnace. Further chapters are devoted to a description of the metallurgical operations involved in the production of alloy steel castings of the kind usually in demand for the motor industry, marine engineering, and aircraft. Next, the use of the electric furnace as an auxiliary of the cupola for the further refining of cast-iron is dealt with, and finally a number of examples of foundry costs for periods of several months is given.

DEJEAN, P. "*Actualités Métallurgiques.*" 8vo, pp. xii + 284, with 144 figures in the text. Paris, 1925: Dunod. (Price 36 francs.)

The author of this book is one of that brilliant group of scientific workers whose labours have contributed to establish the high reputation of metallurgical science in France, and to whom the technical world owes so deep a debt of gratitude. Among them are to be reckoned such men as Réaumur, Deville, Osmond, Martin, Pourcel, and others. The work mainly consists of a collection of the principal results of the author's own researches carried out in various laboratories during the past twenty years, the more important chapters being those relating to studies on quenching and on ferro-magnetism. By observation of the reactions produced during the cooling of self-hardening steels, the author has succeeded in demonstrating the mechanism of quenching, the speed at which those reactions proceed in the case of self-hardening material being sufficiently slow to enable them to be followed. His results have since been confirmed by other investigators. In explanation of the phenomenon of ferro-magnetism the author has built up his theory of the demagnetising field, a solid basis to which is furnished by a series of experimental results. The book concludes with two chapters of highly practical interest, describing present tendencies in the manufacture and utilisation of special steels, in which tables are given showing the composition of the principal types of structural steel, with diagrams indicating the effect of heat treatment on their tensile properties. The book largely merits attention as showing the value of scientific research when applied to the solving of practical problems.

"*The Engineer's Year Book for* 1926." Being a compendium of the modern practice of civil, mechanical, electrical, marine, gas, aero, mine,

and metallurgical engineering. Compiled and edited by H. R. Kempe and W. Hanneford Smith. 8vo, pp. 2998. London, 1925: Crosby Lockwood & Son. (Price 30s.)

This well-known work of reference, which is now in its thirty-third year of publication, has again appeared in a revised and slightly enlarged form. The usual general revision has been carried out by the editors-in-chief, and the numerous associate editors and contributors have subjected their respective sections to a thorough revision. The consistent and regular annual revision of the book with the co-operation of so many distinguished specialists, whose names are given in the list in the opening pages, has resulted in the production of a work of reference of unique authority, the value of which is now universally recognised.

FRIEND, J. NEWTON. "*Iron in Antiquity.*" 8vo, pp. 221, with frontispiece and 16 illustrations in the text. London, 1926: Charles Griffin and Co., Ltd.

This book is largely a republication of the author's comprehensive memoir published under the same title by the Iron and Steel Institute in vol. xii., *Carnegie Scholarship Memoirs*, 1923. It gives a highly interesting and useful account of the earliest uses of iron by different nations and at different periods of the world's history. The book is well and concisely written, and forms a most valuable addition to the literature on the early history of iron.

GIBBS, W. E. "*Clouds and Smoke: The Properties of Disperse Systems in Gases, and their Practical Applications.*" 8vo, pp. 240, with 31 figures in the text. London, 1924: J. and A. Churchill.

The book is concerned with the study of disperse systems, such as fog, smoke, or flame, in which a liquid or solid substance exists in a highly disperse condition in a gas. For convenience, such disperse systems have been called aerosols. The author aims at giving a clear and comprehensive account of the properties and behaviour of aerosols, and of their practical and industrial applications. The first part of the book is devoted to a detailed consideration of the methods by which aerosols are formed, the general properties of such systems, the movements of the particles, the conditions that determine the stability and the methods by which such properties can be determined experimentally. In the second part, this knowledge is considered in its direct relation to the phenomena of meteorology, the problem of dust explosions, the industrial treatment of fumes and gases, the manufacture of substances in a finely divided condition, and finally, the use of smoke in warfare. The book contains a mass of little known information in a convenient form, and may be commended to the notice of practical engineers and of workers in pure science.

GRENET, L. "*Trempe, Recuit, Cémentation et Conditions d'emploi des Aciers.*" 8vo, pp. 655, with 84 figures in the text. Third edition, revised and enlarged. Paris and Liége, 1926: Librairie Polytechnique. C. Béranger.

The author sets out to devise a simple method of classifying the known phenomena manifested in the working and treatment of steel, which is also intended to serve as a practical guide in determining the heat treatment. Actual descriptions of methods for the study of steel are avoided, the information being confined to the principal results yielded by those methods; but, on the other hand, for the benefit of those engaged in shop practice,

the methods of heat treatment are given in precise detail. The properties of steel as revealed by tensile tests are defined. The definitions of the terms employed in heat treatment are given, and a classification of steels is made according to the temperature of transformation on cooling. A discussion of the influence of heat treatment on the properties is followed by a general description of the methods of treatment, and all that pertains to the carrying out of the operations. Case-hardening is dealt with in a separate chapter. The points to be observed in determining the selection of structural steel are indicated, and finally a section is devoted to the treatment and testing of steel castings, iron castings, and non-ferrous alloys. The work is a valuable aid to those engaged in everyday works practice.

HADFIELD, R. A. "*Metallurgy and its Influence on Modern Progress: with a Survey of Education and Research.*" Pp. xvi + 388, with 71 plates. London, 1925: Chapman and Hall, Ltd. (Price 25s.)

The author is the widely known head of the great firm associated with his name, and is also famous as an inventor, metallurgist, and President of several important and technical scientific societies. He is also a Fellow of the Royal Society. Almost more than any other leader of industry in this country, he has kept in close touch with technical progress in other countries, and enjoys a wide acquaintance with the leading representatives of science and industry throughout the world, so that he brings to the work of compiling a book on metallurgy an exceptionally wide range of experience.

Sir Robert Hadfield is the author of numerous papers embodying the results of scientific research, and these papers and his addresses, in which he has from time to time reviewed the advance of invention, have now been expanded, revised, and supplemented to form the present handsome volume. Part I., mainly historical, is devoted to the work of some of the pioneers of physical science and metallurgy. In Part II. consideration is given to the development and importance of alloy steels. Much information is included regarding modern alloy steels and their applications, the intention being to demonstrate that we are passing out of the age of iron and simple steel and are advancing into an era which may justly be termed an age of alloy steels, for without such steels many operations and activities of modern life could not now be carried on. Part III. discusses the importance of fuel economy and the progress made in recent years towards the realisation of a better and more economical use of the fuels available in industry. Part IV. deals with facilities for education and research, and is largely devoted to an account of the leading technical and professional societies, with notes on institutions for the training of metallurgical students, and brief mention of institutions specially designed for research in metallurgy. As an appendix the author has included a verse translation by L. P. Sidney, based on a French translation by F. Osmond of an eighteenth-century Latin poem, "Ferrum," originally composed by the Reverend Father Xavier de la Sante, Member of the Society of Jesus. The poem has not hitherto appeared in an English version.

"*Hütte: Taschenbuch der Stoffkunde.*" Compiled by the Akademische Verein Hütte E.V. Berlin, and by Dr.Ing. A. Stauch. 8vo, pp. 1173, with 356 figures in the text. Berlin, 1926: Wilhelm Ernst & Sohn. (Price 25.80 marks.)

The book is a companion volume to the "Mining Engineer's Pocket Book," "Metallurgist's Pocket Book," and "Engineer's Pocket Book," issued respectively in 1923, 1924, and 1925, and it forms one of the same

series. As in the case of the previous publications, this Pocket Book of the technology of materials has been compiled with the collaboration of a number of specialists, and with the assistance of Committees of the Verein deutscher Ingenieure. The book is a compendium of the mechanical and physical properties, the composition, treatment, and working of mainly the materials of construction, and the method of testing them. The first half of the work deals with inorganic substances, such as metals, both ferrous and non-ferrous, non-metallic materials and their compounds, sulphur, phosphorus, carbon, acids, cement, mortars, ceramics, glass, and grinding agents. A consideration of organic substances, such as textile materials, wood, paper, cellulose, derivations, vegetable oils, rubber, resins, varnishes, woollen fibre, leather, gelatines, glue. Another section discusses the derivatives of fossil plants and animals, including coal and its by-products—coke, tar, mineral oils, and lubricating oils. Lastly, a chapter is devoted to explosives both propellant and for blasting. Like its predecessors, the book contains a vast store of practical information and constitutes a most useful work of reference to all engaged in mechanical engineering or architectural work.

MONYPENNY, J. H. G. "*Stainless Iron and Steel.*" 8vo, pp. 304, with 22 plates and numerous figures in the text. London, 1926: Chapman and Hall, Ltd. (Price 21s.)

Stainless steel in the form of a high-chromium steel alloy was first introduced to the public in 1914 in the form of table cutlery, and its almost exclusive use for cutlery purposes for a considerable time led to the belief—still widely held—that stainless steel is simply a special type of cutlery steel with a limited range of mechanical properties. There is, however, a whole range of steels which come within the category of stainless steels, whose mechanical and physical properties vary in a manner similar to the variations met with in the different ranges of ordinary carbon steels, but all of which have the distinguishing property of great resistance to corrosion, due primarily to the presence of a considerable percentage of chromium. The credit for the discovery of this important characteristic of high-chromium steels belongs to Harry Brearley. The applications of the corrosion-resisting material known as stainless steel have now become so widespread, and the types of such steel are so varied, as to justify the preparation of a book devoted entirely to the consideration of what many suppose to be a single type of steel. The subject is dealt with under the headings of "The Influence of Chromium on the Structure and Hardness of Steel," "The Manufacture, Working, and Treatment of Stainless Steel," "The Mechanical and Physical Properties of Stainless Steels in Relation to Varying Treatment and Composition," "The Effect of Varying Treatment and Composition on the Resistance to Corrosion, and to Various Types of Corroding Media." Special attention has been devoted to the micro-structural characteristics of stainless steel, and in order that the account may be as informative as possible to those who have not specially studied metallography, the author has endeavoured to make use of the simplest terms, with very creditable success.

SACHS, G., and G. FIEK. "*Der Zugversuch.*" 8vo, pp. 252, with 202 figures in the text. Leipzig, 1926: Akademische Verlagsgesellschaft m.b.H. (Price 15 marks.)

This book is entirely concerned with the principles and applications of the tensile test as applied to the testing of metals, with indications as to the proper interpretation of the results. The book is divided into three parts, the first of which consists of a discussion of the theory of the tensile test

and of the tensile properties, such as elastic limit, yield point, elongation, influence of notches, and relation of the tensile test to other kinds of tests, and the mechanical principles involved. A chapter on the influence of component stress is appended, not alone on account of the importance of this question, but partly out of consideration of the fact that there is no recent study of it to be found in existing literature. Owing to the mathematical treatment of the subject, which is of necessity involved, this portion of the work may be more difficult for the student to follow than the remainder of the book.

The second part is an exposition of the nature and structure of metals, and the manner in which the structure is affected by the application of the test to the material, with a consideration of the properties of crystals, the hardening effect and other changes due to cold-working, the after-effects of straining, internal stresses, and fatigue phenomena. Finally, the author presents a complete and well-illustrated description of testing appliances, indicating which are the most serviceable for any particular purpose. In an appendix a description with fully dimensioned illustrations of the standard test-bars in use in different countries is given. A most useful addendum is a table of definitions of values accepted in different countries for the limit of elasticity, yield point, and limit of proportionality.

TRINKS, W. "*Industrial Furnaces.*" Vol. II.—"Fuels, Furnace Types, and Furnace Equipment; their Selection and Influence upon Furnace Operation." 8vo, pp. 405, with 292 figures in the text. New York, 1925: John Wiley & Sons, Inc. London, 1925: Chapman and Hall, Ltd. (Price 27s. 6d.)

This volume is a continuation of the first one published in 1923, which dealt largely with the theory and appealed mainly to the designer of furnaces. The present volume is devoted primarily to practice and the details of design and equipment of furnaces. The selection of fuel best suited to particular cases is first considered, and a chapter is devoted exclusively to a discussion of the equipment used to burn different fuels or to convert electrical energy into heat, including devices for controlling furnace temperature and atmosphere. Based on the preceding chapters, a critical comparison of furnace types and fuels is then presented in order to facilitate the selection of the right type of furnace and the right kind of fuel to suit the conditions of any specific case. The work is intended to appeal specially to engineers of furnace equipment, furnace construction, and furnace operators.

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